1-1-2003

Virtual learning environment for watershed science education

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Virtual learning environment for watershed science education

by

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A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Water Resources

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Iowa State University
Ames, Iowa

2003

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Signatures have been redacted for privacy

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ACKNOWLEDGEMENTS

I would like to thank my family for their love, support, and understanding as I follow my dreams and especially for their support in completing this task. Thank you for everything. Of course all this would have been impossible without Tina, my wife.

I would also like to thank my friends and co-workers: Hardeep Bajwa and Amritpal Kang, for their advice, constructive comments, and technical support in completing this project.

I would also like to thank my committee members: Dr. Roy Gu and Dr. Steven K. Mickelson for their guidance in this research. Finally, I would like to express my appreciation to my major professor, Dr. U. Sunday Tim, for his guidance and advice during this study. His enthusiasm, constant motivation and support helped me tackle the difficulties I faced in this research and stay at Iowa State University.

CHAPTER 1. GENERAL INTRODUCTION

1.1 Introduction

The Earth is a place of change. The geologic record testifies that the earth's environment has been subjected to change over eons – much of it occurring over the centuries, but some relatively rapidly over the decades. Over the centuries, mountains have changed to plains, areas once fertile have turned to desert and so on, but these were the natural events over which man had little or no control. The influence of the humans - newest entry to the list of agents of environmental change has been profound during the second half of the 20th century, and is bound to increase over time.

The ever-increasing human population along with the increase in the power of human technology has resulted in an immense increase in the impacts of human activities on the global environment. In every corner of the world, people are cutting forests, extracting minerals and energy supplies, eroding topsoil, polluting the air and water, creating hazardous waste, and disrupting natural areas at a rate unprecedented in the history of life on earth. As the pressures from overpopulation and development increase, it is becoming increasingly difficult for people to provide for their needs and wants. It is also becoming impossible to escape the consequences of severe environmental degradation: species extinction, habitat fragmentation, chemical contamination, increasing public health problems, starvation, poverty, and loss of human life. Many experts believe that if the current rate of destruction continues, we will see the gradual breakdown of the very systems that support life on earth (Braus *et al.*, 1993).

In the US, national concern over the quality of the environment has increased significantly over the past several decades. This is evidenced by the passage of major legislation such as the Clean Water Act, Clean Air Act, and National Environmental Policy Act (IEQ, 2000). The creation of national, regional and state agencies involved in monitoring and maintaining environmental quality supports the growing awareness of how humans have impacted the natural environment.

Although the scale of the problem of environmental change is shifting from local to regional and even to global ones, yet the idea of global resources being limited, and the global environment being threatened, is difficult to comprehend when human interactions occur at a very local/regional, small scale. Along with using the best available technologies and the data collected over the years to counter or control the destruction of our environment, the people need to be educated about their environment. Environmental education will help the people gain the knowledge, skills, motivation, values, and commitment they need to manage the earth's resources sustainably and to take responsibility for maintaining environmental quality.

Today's environmental problems require more creative, comprehensive solutions. According to US Environment Protection Agency (EPA), the approach to accomplish this is using a watershed based management to further restore the physical, chemical, and biological quality of our environment. The EPA defines the watershed approach as "a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically defined geographic areas" (EPA, 1996). A report by the National Research Council (NRC) also noted that a watershed approach "uses sound scientifically based information from an array of disciplines to understand the factors influencing the terrestrial and aquatic ecosystems, human health and economic conditions of the watershed" (NRC, 1999). The watershed is thought of as the integrating focus and object, the most appropriate spatial organization and functional unit for managing ecological problems, such as those related to agriculture, silviculture, mining, urbanization and recreation or the interactions between natural, anthropogenic and human factors. The watershed approach also strengthens teamwork between the public and private sectors at the federal, state, tribal and local levels to achieve the greatest environmental improvements with the resources available. Through such active and broad involvement, the watershed approach can build a sense of community, reduce conflicts, increase commitment to the actions necessary to meet societal goals and, ultimately, improve the likelihood of sustaining long-term environmental stewardship. However, despite the environmental importance of watersheds, the national demand for watershed education and training far outstrip the availability of learning materials and resources (EPA, 2002). The successful management of environmental problems will require innovative educational programs in watershed science, new modalities that expand undergraduate earth and environmental sciences education beyond traditional lecture and lab settings, and the strengthening of watershed training programs to provide skilled workforce who can make informed environmental planning decisions (Tim, 2001).

Environmental education has been evolving for many years. Today it has become imperative that the colleges and universities modify their curricula to impart the students with adequate knowledge of earth and environmental sciences. The revolution in information and communication technologies (ICTs) has shaken the foundations of higher education and life-long learning in general. Efforts to use computers as "teaching machines" date back at least as far as the early 1960s when the first explorations of computer-assisted instruction began. This view of the computer as a deliverer of instruction continues to dominate many people's thinking today, even though technological advances and changing perspectives have expanded the realm of possibility considerably (Lehman, 1995). Undergraduate education, utilizing these new technologies, which involves active student participation and inquiry based pedagogy, will be the key to developing a workforce and environmentally literate citizenry who can critically evaluate issues related to environment and natural resources.

1.2 Research Objectives

This research is focused towards the creation and development of a set of interactive, student centered, inquiry-based online learning modules that enhance watershed ecosystem science education and make undergraduate students and graduates scientifically more literate citizenry, able to critically analyze the multitude of environmental problems facing society. The basic aim of this research was to create learning materials that lead students through problem-solving exercises involving real-world watershed management problems and integrates modern technologies to provide a richer vision of complex environmental processes and concepts. The specific research objectives were to:

1. Create a series of interactive online learning/instructional modules ("courseware") that improve the watershed science education of undergraduate students and engage

them in inquiry-based, active learning pedagogy through exploration of complex environmental processes.

2. Develop online simulation and visualization tools that would allow the students to examine various environmental processes and allow for what-if analysis.

3. Demonstrate the constructivist learning pedagogy through use of the learning environment.

1.3 Thesis Organization

The remaining sections of this thesis are organized as follows. Chapter 2 provides a general overview of the Virtual Learning Environments (VLEs), their features and also emphasizes on the need for VLEs in Environmental Science Education. Chapter 3 starts with a discussion of the Client/Server architecture and then goes on to describe the architecture and key features of the VLE developed for Environmental/Watershed Science education. Chapter 4 is an example application of the VLE that describes how a student trying to learn the concepts and processes related to Watershed Science can use it.

CHAPTER 2. VIRTUAL LEARNING ENVIRONMENTS

2.1 General Overview

The founders of modern universities built institutional structures and practices around the centrality of libraries in providing teachers, researchers and students with access to books and manuscripts. The revolution in information and communication technologies (ICTs) has changed how people can gain access to information in ways that have shaken the foundations not only of the library, but also of higher education and learning in general. Various teaching methods using the Internet and multimedia have been introduced. Most of these methods emphasize, in particular, on the aspect of collaborative communication between learners and instructors during interactive teaching/learning activities (Brna 1997). For long, colleges and universities have offered opportunities for students to take courses from a distance but today, the Web and other ICT advances have led universities and companies to launch online learning initiatives that have implications well beyond distance education.

Over time, the successes of key initiatives are enabling the restructuring of higher educational institutions and practices in ways that might restructure traditional campus-based institutions of higher education. These initiatives include new universities, such as the Globalwide Network Academy (GNA), one of the first online universities with no physical center providing courses over the Internet, the US Army's Virtual University (eARMYU), the University of Phoenix Online, and Jones International University (JIU), the first fully accredited virtual university.

Advances in ICTs, like the World Wide Web (or simply the Web), enable new forms of access to information, including the ability to search, filter and obtain multi-media information; to participate in drills and practice skills with immediate, personalized feedback; and to visualize processes and learn-by-doing in ever more realistic simulated environments. They also permit access to people, for example by networking students, teachers and experts.

2.2 Virtual Learning Environments (VLEs)

Following the emergence of the Internet in the early 1990s, many new tools and products have been developed to exploit its benefits fully. Some of the major benefits offered by the Internet include universal access, new ways of communication and assessing for the students and the instructors. The products which have been developed to support the teaching and learning activities on the Internet are usually termed as the Virtual Learning Environments (VLEs). Most of the people tend to link virtual reality with the immersive environments, which are developed using computer graphics. This is true, but has a limited application in the field of education owing to the current high costs of the hardware and the software required to develop such environments. Engaging and exciting learning environments can be created two-dimensionally using pre-recorded video, graphics and animation imbedded in an exploratory program (Follows, 1999). Even better results and a wider reach of the learning environments can be attained, if these are made accessible to the intended audience through the Internet. A virtual learning environment (VLE) is software that provides a shell or framework for putting a course online. It can be defined as an integrated software system that combines in a single package facility for the delivery of learning materials, communication, assessment, and student feedback. It can be online, offline or a hybrid system. Generally, VLEs provide a convenient way to create online courses for either remote or local delivery that can be run as stand-alone course modules or in support of traditional teaching. There are a number of different commercial packages as well as packages produced by individual universities and national projects. Most VLEs have these key features wrapped in a single package:

- *Delivery of learning resources and materials* – e.g. through the provision of lecture notes and supporting materials, images and video clips, links to other Web resources, online discussion and assessment activities.
- *Communication between tutors and students* – e.g. e-mail, discussion board and virtual chat facilities, which support various types of communication: synchronous and asynchronous, one-to-one, one-to-many and many-to-many.
- *Self-assessment and summative assessment* – e.g. multiple-choice assessment with automated marking and immediate feedback.
- *Additional Support* – could take the form of communication with tutors or other students, provision of supporting materials such as course information and Frequently Asked Questions (FAQs).
- *Restricted access* – e.g. usernames and passwords to ensure that only registered students can access the course.
- *Consistent and customizable look and feel* – a standard user interface that is easy for students to understand and use. Courses can be individualized with colours, graphics and logos, but the essential mode of use remains constant.

- *Navigation structure* – structured delivery of information supported by a standard navigation toolbar. Most VLE software assumes that students will work their way through linear sequences of instructional material. Others are more flexible and will accommodate alternative information structures, e.g. multi-path case studies.

VLEs provide the course developer with a wide range of applications, the choice of which depends on the style of learning that is to be achieved. Some courses requiring substantial interaction between students might need synchronous chat facilities and collaborative working; others would be designed for individual independent study; others might use a synchronous threaded discussion list and a large amount of course material, with the computer aided assessment element providing formative assessment. It is important to note that VLEs provide the tools but it is up to the course developer and course tutors to make it an effective learning environment.

Some VLEs, such as FirstClass and Lotus Notes require software to be installed on each machine that accesses the course. There are cost and logistical implications in this approach. More flexible are VLEs that can be delivered over the Web and require no specialized client software. The VLE software runs on a server and all the course developers, tutors and students need is an Internet connection and a Web browser.

Typical web-based virtual learning environments such as Virtual-U (VLEI: http://www.vlei.com) and WebCT (WebCT: http://www.webct.com) include course content delivery tools, synchronous and asynchronous conferencing systems, polling and quiz modules, virtual workspaces for sharing resources, white boards, grade reporting systems, logbooks, assignment submission components and so on. Several prestigious schools, such as Stanford, Berkley and MIT, have developed their own systems to deliver course material online. Stanford Online (http://stanford-online.stanford.edu/) offers course notes for download, and videos of lectures that can be viewed live or downloaded.

Very successful and innovative educational projects, sponsored by USDA-CSREES (HEP), NSF, and many other organizations have developed numerous examples of rich, learner centered educational materials and digital collaborative learning environments. These learning environments feature a variety of advances including tools for simulation, modeling and visualization; large datasets; remote access to spatial analytical tools; and network supported collaboration.

2.3 Levels of VLE use

A useful framework for considering different ways of using VLEs to support or deliver courses is one developed by Mason (1998). Mason identifies three models:

- *Content and support model* – where pre-prepared content is delivered in print or online, and support is provided online. Content and support are not integral to one another – that is, online support is an optional extra and is not integrated into learning activities. This model is relatively easy to establish but does not fully exploit the benefits of online learning.
- *Wrap-around model* – where there is a mixture of pre-prepared content and online learning activities. The learning activities involve online discussion and collaborative activities.
- *Integrated model* – where most of the learning takes place via collaborative online activities and content is largely determined by the learners either individually or as a group. Learning is very much student centred and highly collaborative.

Figure 1 shows how VLEs might support teaching. This support may range from simple uses of a limited range of tools to support face-to-face courses, through to entirely online courses that make sophisticated use of a wide range of the VLE's facilities. Figure 1 gives some examples of how VLEs can be used, and shows the possible range in their levels of sophistication. These uses can be combined as appropriate to local needs. The instructor might start by using just one or two of the features of the VLE and then develop a more sophisticated model as he/she becomes familiar with the system and what it can do (Cook,1999).

Simple		*Posting course information and existing course materials*
		Including links to other online materials
		Communication between students, lecturers and outside contributors
		Providing a 'shell' for computer-assisted learning resources
		Assessment – self-assessment and end-of-term exams
		Integrating online activities, support and materials with lectures and seminars
		Collaborative student projects
Complex		*Delivering complete online courses with fully integrated activities, e.g. distance learning courses*

Source: Based on a model by Cook (1999)

Figure 1: Levels of use of a VLE in support of teaching

2.3.1 Posting course information and existing course materials

The most elementary use of the VLE by the instructor is to use it to post the course notes, lectures, slides and the assignment details. This gives the students the freedom to access these materials whenever and from wherever they want to. One of the major benefits of doing this is that the students can review the lectures or the material covered in the class at a later time. Materials can be periodically uploaded into the VLE, which acts as a course archive. The use of a well-designed folder structure allows material to be organised for all students or specific groups. However, simply using the VLE as an electronic filing cabinet may not enhance the students' total learning experience. There is a need to be selective in what is included within a VLE course and be clear about the aim of including the material.

2.3.2 Including links to other online materials

The Web is a rich source of the current or up-to-date material on almost every subject. Providing links to these materials through the VLE would allow the students to tap this rich source. The instructors should encourage this practice as this promotes active learning on part of the students and helps them develop the research skills. The VLE could have a special section where the instructor could post the links or the instructor could provide these through the discussion boards. Students can also be given permission to post links to the relevant subjects. This is an excellent way of encouraging students' research skills and creating new resources that can be used elsewhere.

2.3.3 Communication between students, lecturers, and outside contributors

Communication tools usually include noticeboards, discussion boards, virtual chat and e-mail. A common discussion board for a particular course avoids the repetition of questions by the students and saves a lot of effort on part of the instructor. This has the potential to encourage peer support, although it is important to set ground rules and to consider how to moderate the board. Providing the virtual chat facilities and e-mail also increases the interaction between the students. These facilities are even more important for pure distance learning where the chances of a face-to-face interaction with the instructors are limited. The communication facilities also provide the students with a chance to collaborate on certain projects or learning activities.

2.3.4 Providing a 'shell' for computer-assisted learning resources

A whole range of interactive learning material, simulations and models exist freely on the Web. A benefit of VLEs is that they allow the instructor to embed computer-assisted learning programs such as simulations or interactive tutorials into the course site, which provides a ready-made structure for the materials. In addition to the material available on the Web, simulation models can also be developed in-house and put on the VLE. These can be supplemented with online quizzes and other supporting material.

2.3.5 Summative and self-assessment

Many VLEs allow the creation of question databanks that can then be used to generate self-assessment quizzes and end-of-term exams. The standard types of question include multiple choice, multiple answer, true/false, matching and ranking. Regular and meaningful feedback is recognised as improving student motivation as well as providing students with information about how they can improve; Laurillard (1993) argues that feedback is essential if the learner is to succeed. All test results in VLEs are automatically analysed by student, by test and by question, and can be easily exported to Excel for further analysis. This is very helpful for diagnostic purposes and can save time in the long run when used with large groups of students (Pollock *et al.*, 2000). Pollock *et al.* also conclude that writing questions suitable for higher-order learning is a time-consuming activity that requires considerable skill.

2.3.6 Integrating online activities, support and materials with lectures

Lectures can be followed up through online tutorials that end with self-assessment, perhaps with an emphasis on topics that students find problematic. At the end of every section a "Concept-Activity" can be included, the completion of which allows the student to have a better understanding of the topic being covered. Additional support to address problems could be provided via a discussion board.

2.3.7 Collaborative student projects

The tutor can use a VLE to set up a task and to answer students' questions about this task. Students may then use communications tools to work on the task together, share files and post their own pages. Usually there is also a facility to put students into groups with access to their own discussion board and virtual or real-time chat facilities. This opens up the potential for collaborative projects and communications between different groups of learners.

2.3.8 Delivering complete online courses with fully integrated activities

A VLE can be used to present all course materials and as the sole medium for communication between tutor and students, self-assessment, monitoring of progress, and submission and return of assignments. Communication and feedback are integrated with content delivery through the activities posted on the VLE. The argument for using a VLE in this comprehensive fashion is that it gives more control to learners and that this will, in turn, enhance learning. One of the advantages of learning online is that, by putting students in control, it places the onus on them to actively engage in tasks. They must do the searching, make the decisions, interact with the multimedia, contribute to the conferences and solve problems. Such things should not be done for them when they operate in the online environment. (Lander, 1997)

2.4 Traditional Learning vs. e-Learning

In traditional classroom teaching, students can pose questions or comments to the instructor, interact by verbal discussion, or work in small groups. Such training is teacher centered and information tends to flow from the teacher to students (Figure 2). It is mainly a one-to-many learning process. Today, the forms of activities that are frequently suggested as necessary and sufficient conditions for effective learning, particularly for university courses, are those with a high degree of interactivity. Online learning focuses more on the students as information often flows to students from the system. It appears to be one-to-one learning environment. Figure 2 indicates a shift from teacher centered learning to student centered learning. For e-Learning, the student receives knowledge from the lectures provided by the lecturer and also searches for his/her own information on the Internet. He/She will have interactions with fellow students through electronic forums, bulletin boards and group projects. He/She can also interact with the lecturer through emails and during limited on-campus tutorials if any. The student is continuously evaluated through examinations and his/her participation in activities such as forum discussions, online quizzes, exercises and Q&A. The server computer monitors and records the time spent and the activities done while the student logs in the course.

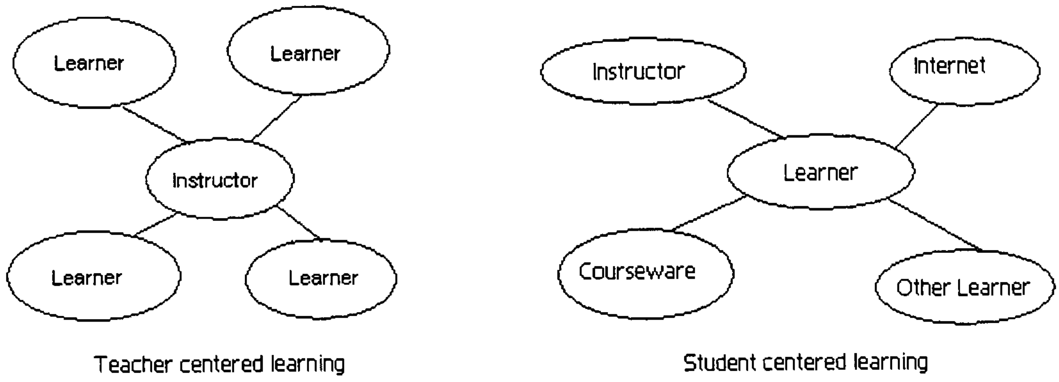

Figure 2: Moving towards learner centric

Since the e-Learning process requires the learner to become the center of focus, the role of the lecturer, becomes that of a facilitator and a mentor, rather than that of an instructor or a teacher. The mentor stimulates the learners online, updates the materials, and answers questions posed by the learners through various channels. Once in a while, the mentor may meet all learners for discussions when they will benefit from face-to-face interaction. This approach emphasizes user-friendliness, and interactivity. Courseware, instructional design, and all learning resources are tailored to fit the needs and constraints of a client or user's specific requirements, with enhanced human interaction rather than dehumanizing the training and learning processes.

In traditional learning environments the information is structured linearly, whereas in virtual learning environments using the ubiquitous Internet the lecture can be reduced to text and graphics and then put in a succession of World Wide Web pages. Although they can still be arrayed in linear order, hypertext may be structured in many other shapes as well. A link to an example may be viewed or skipped. Now the learner has control of many aspects of the presentation. They choose which pages to visit and in what order; the experience is now primarily in the hands of the learner. In this way the virtual learning environments may be superior to either a traditional textbook or a traditional lecture. Another option that the virtual environments give is the one wherein the learners can experience their education in a "learn-by-doing" way. Table 1 lists some of the advantages and disadvantages of using a VLE.

Table 1: Advantages & Disadvantages of using a VLE

Advantages of using a VLE	Disadvantages of using a VLE
• Learning materials can be accessed anywhere and at any time	• The online access can be slow due to slow data transfer online
• Learning material can include text, graphics, videos etc.	• The VLE can become a "dumping ground" for unwanted material
• Maintain currency of the learning material	• The learning material can become outdated without periodic upgrading.
• Promotes "active learning".	• Not good for "passive learners"
• Comprehensive coverage of key topics	• Learning can become very complex if not properly structured
• Allows for student-student and teacher-student interaction	• Can result in instructor overload if not properly structured
• Allows for self-assessment	• Self-assessment is not of much use if not coupled with instructor's assessment of the student's progress

2.5 VLEs and Environmental Science Education

Whether the society will be capable of efficient management of its vital natural resources to ensure sustainability and a higher quality of life for present and future generations depends largely on the strength of the educational system for earth, biological, and environmental sciences. Knowledge about the environment in general and watershed ecosystems in particular is transferred to the student and the resource manager of the future at colleges and universities. However, undergraduate science and engineering programs at major colleges and universities across the United States usually do not specifically educate or train students in the interrelated disciplines of watershed management and environmental/natural resource problem solving (Tim 2001). Even graduates in earth and ecological science disciplines are often inadequately trained and are inexperienced in new technologies and approaches of solving ecological problems within watersheds. In particular, curricula and course offerings areas such as management, watershed hydrology and nonpoint source pollution control at many American colleges and universities are highly fragmented and opportunities (through hands on activities) and resource materials for students to engage in collaborative, experimental learning are typically limited. Thus, undergraduates lack opportunities to, for example, learn about hydrologic implications of land-use change, agricultural nonpoint source (NPS) pollution, wetlands and sedimentation, at least in the most introductory courses in earth and environmental science courses. Only a few textbooks are available in this field, and specialists write these books for advanced students. Because, of the limited market, there are almost no comprehensive teaching/learning materials available to the instructor. To prepare lectures, case studies and interactive hands-on exercises, instructors must have intimate familiarity not only with the scientific literature, but also with tools, models and technologies associated with watershed management. Indeed curricula and pedagogy must be enhanced to meet three primary goals: (1) education and training of future scientists, engineers, and resource managers who will work to advance understanding of human impacts on ecosystems, (2) education of future leaders who will determine policies and management actions that are commensurate with the environmental and human health protection grab, and (3) training of responsible citizens through distance and virtual learning opportunities who value earth's system and understand the unique role of watersheds within the human biophysical and social contexts. To archive the breadth of ecosystem management perspective and to couple that perspective with prudent stewardship of the nation's environment and natural resource systems authentic digital learning environments at undergraduate level must be designed, implemented and evaluated.

CHAPTER 3. DIGITAL LEARNING ENVIRONMENT FOR WATERSHED SCIENCE EDUCATION

This chapter begins with a discussion on the client/server architecture, and the comparison of the two basic types of this architecture. The focus then shifts towards the design of the system used to develop the virtual learning environment for watershed/environmental sciences. Finally the chapter provides a documentation of the various modules included in this learning environment.

3.1 Evolution of Client/Server Computing

The corporate computing era began with centralized systems, also known as the host-based processing environments. Host-based application processing is performed on one computer system with attached unintelligent, "dumb" terminals (Berson, 1996). Client-server architecture only became a reality with the advent of personal computers (PCs). Over the years, personal computers started to replace these dumb terminals but the processing continued to be done on the mainframe. The improved capacity of personal computers were largely ignored or used on an individual level. With so much computing power idle, many organizations started thinking about sharing, or splitting, some of the processing demands between the mainframe and the PC. Client/server technology evolved out of this movement for greater computing control and more computing value.

3.2 Client/Server Architecture

Webster states that architecture is "the art and science of designing and erecting a building." Within the context of information systems we could then say that client/server architecture must be an approach to the design of an information system. There appears to be a general agreement that client/server architecture is an approach to the design of a software application that decomposes the application into a small number of server functions that provide commonly used services and a large number of client functions that perform more narrowly defined work in reliance on the common services provided by the server functions. Usually a typical application can be subdivided into three parts: the Graphical User Interface (GUI), the logic, and the database. The relationship between these three elements is that one element makes a request to the other element and the other element then fulfils these requests. This making and fulfilling of requests is called a client/server computing (Shan and Earle, 1998) (Peng, Tsou, 2003). The three elements could reside on the same machine or on different machines. Therefore, the client/server architecture can be defined as the decomposition of an information system into server functions, possibly executing on multiple hardware platforms and providing commonly used services to a large number of interconnected client functions executing on one or more hardware platforms. Some of the common features of client/server architecture are:

- A Client Server System is more structured than general distributed computing
- A client sends request to servers to execute tasks
- The tasks may be just to provide information, or to perform a complex computation (perhaps returning information)
- Client and servers are asymmetric
- A server may be a client of another server

3.2.1 Client/Server Architecture as a Design Approach

This approach designs an application so that the functional components of an application are partitioned in a manner that allows them to be spread across, and executed on, multiple different computing platforms sharing access to one or more common repositories of data.

Client/Server architecture is therefore a design approach that distributes the functional processing of an application across two or more different processing platforms. The phrase "client-server" reflects the roles played by the application's functions as they interact with one another. A server is a unit providing services to requesting processes. Generally it does not send information to the requester until it is told to do so. The processes that send the request for a service from the server are termed as the clients. The clients initiate the transaction with the server and are therefore the more active partners in this association. Some of the client server properties are:

- Clients and servers are separate processes
- They may run on the same or different machines
- Each process can hide internal information
- Each process can implement its own set of business rules
- They communicate by peer-to-peer protocols

The client/server software architecture is a versatile, message-based and modular infrastructure that is intended to improve:

- *Interoperability* – Allows different systems to exchange meaningful information.

- *Usability* – the ease with which a user can learn to operate, prepare inputs for, and interpret outputs of a system or component
- *Portability* – A system in one environment can be installed in another.
- *Scalability* – the ease with which a system or component can be modified to fit the problem area.
- *Integration* – Share and exchange information without external intervention.
- *Transparency* – The user can read information from a site without knowing where it is.
- *Security* – The user is protected against other users and external agents.

3.3 Web-Based Applications

Web-based applications employ Web technologies (i.e., Web browsers, HTML, HTTP) to provide value. These applications can be simple HTML applications that retrieve and display HTML pages or sophisticated corporate applications that integrate Web with corporate resources. We can categorize these applications into the following classes:

- Static HTML-based applications
- Server-side (CGI-based) applications
- Client-side (Java-based) applications

3.3.1 Static HTML-Based Applications

In the early days of the World Wide Web, serving static HTML was the dominant form of content. These applications, shown in Figure 3, basically retrieve and display the

HTML documents that reside on the Web server site. It is up to the creator of the application to determine how the different pages would be linked to one another. The users can navigate the web site through the hyper linking capability provided by HTML. A large number of Web sites whose main goal is to just present information to the clients use this application model.

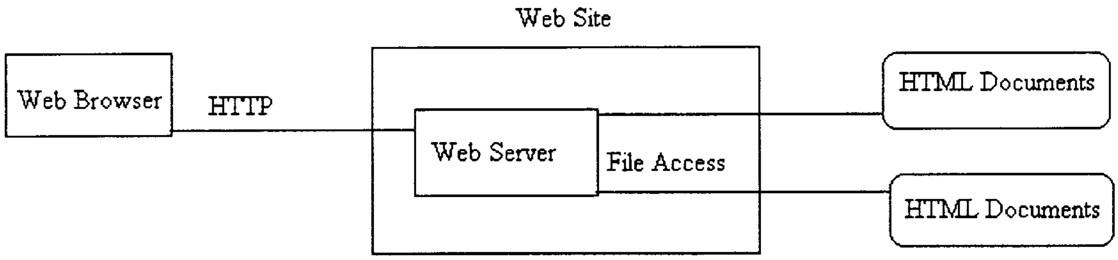

Figure 3: Static HTML-Based Applications

HTML prepares the media type that the Web browsers understand. HTML is a cross-platform documentation language – any computer equipped with a Web browser can read and display HTML documents. The idea behind HTML is that if parts of the document are marked using functions then any browser or computer anywhere in the world should attractively and correctly display the document. HTML documents are created as ASCII text files by using HTML markup tags or by using HTML filters that convert word processing documents such as Microsoft Word into HTML. HTML tags are used to indicate headings, italics, bolds, ordered lists, and places where graphics, sound bytes, and other pieces of information can be located in the document.

Hypertext and hypermedia are at the core of HTML and WWW. Being able to link the web page to other pages is the most innovative and compelling aspect of the web and it is certainly a huge part of the Web's success. Links are convenient – and also exciting – since they provide related information to anyone viewing the page. A ***hypertext*** is a series of documents, each of which displays atleast one visible link on the screen, called a ***hypertext link***, to another document in the text. ***Hypermedia*** extends hypertext in two ways: it incorporates multimedia into hypertext documents, and it allows graphic, audio, and video elements to become links to other documents or multimedia elements. ***Hotlinks*** are the main distinguishing feature of hypertext, hypermedia and HTML. Use of HTML allows a person to browse through Web documents in a manner similar to, but more powerful than, browsing through a library – the person can click on a hotlink and get access to the needed page/document that may be located anywhere on the web.

HTML capabilities include basic features as well as "fill-in forms" for sending search arguments, comments and other pieces of information to the Web servers. The fill-in form capabilities are provided by the FORM statement. A FORM is simply a collection of fields of information. These fields of information come in various varieties, such as text boxes, radio buttons, pulldown menus, and other elements. A FORM also contains a button to submit the form (which simulates submitting a form in the real world), and a button to clear the user's input so that the form can be used again. The browser uses the FORM statement to construct a URL and data that are sent to Web server. The Web server passes this information to a script that performs the needed operations and returns the results back to the client.

3.3.2 Client-Side (Java-Based) Applications

Java is an object-oriented programming language that is playing a unique role in WWW. Java programs come in two main types: applications and applets. Applets are Java programs that a client can download and run in their own Web browser. This is the reason that Java has gained so much popularity in building Web applications across the Internet. Java was introduced by Sun Microsystems and is similar to C++ but draws heavily from other object-oriented languages such as Eiffel and Smalltalk.

An applet is an application designed to be transmitted over the Internet and executed by a Java-compatible Web browser. The applet is actually a tiny Java program, dynamically downloaded across the network, just like an image, sound file, or video clip. The important difference is that an applet is an intelligent program and can react to user inputs and change dynamically, not performing the same actions over and over again. There are several implications of this:

- Java applets exemplify "downloadable code" that is developed at one site and is migrated to another site on demand. This introduces several security issues but also creates many interesting research opportunities.
- Java applets make Web applications really client/server, because the Java code can run business logic on the Web client site.
- The Web screen layout can be changed dynamically based on the user type. A Java program can determine the user type and modify the screen layout.
- The user can produce graphs and charts dynamically at his/her browser instead of fetching predefined graphs and images from the Web server.

- Many Web browsers are configured to disallow remote connections from Java applets because this increases security risks.

The browser can, however, be configured to allow Java applets to invoke remote operations if the security concerns have been taken care of. If allowed, the Java applet can ask the user to issue a query and then send this query directly to a remote application or database (Figure 4).

This is especially interesting for database gateways where the database gateway functionality could run on the client side. A standard called JDBC has been developed to allow Java programs to issue calls to relational databases. In addition, Java applets can use CORBA or Sun Microsystem's Remote Method Invocation (RMI) to invoke remote interactions. If restricted, the Java applets can issue remote resources through the Web server. However, it is difficult to convert large-scale applications into Java applets.

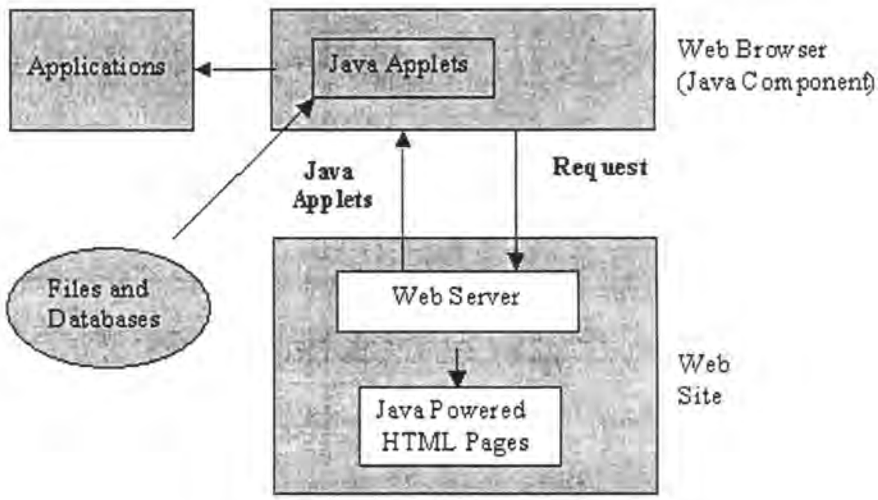

Figure 4: Java-Based Applications

3.3.3 Server-Side (CGI-Based) Applications

The CGI (Common Gateway Interface) is a program that resides on the Web server. This program, usually known as a CGI gateway, can be a script (e.g., a UNIX shell script or a Perl script) or an executable program (C or C++ code). After this program has been written it is readied for execution by the Web server (this step typically involves placing of the CGI program in the /cgi.bin/directory or another designated library of the server). Hyperlinks to the program can then be included in the HTML documents in the same way as hyperlinks to any other resource. For example, if the CGI program is called "method.pl", the URL for this program is

http://www.theserver.com/cgi.bin/method.pl

The CGI scripts like these can be embedded within the HTML page to create dynamic web pages. The HTML pages in their simplest form can be only used to present information, not performing any specific actions based on the user inputs. The CGI scripts provide this functionality to the web pages. The URL for the CGI script is included in the HTML page at an appropriate place, usually as the ACTION attribute's value. For example, we can write the following HTML statement to invoke *method.pl:*

<FORM ACTION="http://www.theserver.com/cgi.bin/method.pl">

When the user submits the form by clicking on some button provided on the Web page, the CGI program URL along with the user inputs are passed to the Web server. The Web server locates the CGI program in the /cgi.bin/directory and executes it. The output produced by this program is sent back to the Web browser. In general, CGI gateways fall into two categories:

- *Single-Step CGI Gateway* – An application program is executed as a CGI executable itself. In this case, the CGI executable contains the application logic invoked by the Web client.

- *Two-Step CGI Gateway* – An application program runs as a daemon process. A CGI executable just dispatches the request to the main application. It may also pre-process the user inputs on the web page into a format suitable for the main application to be run. In this case, the CGI gateway has no logic and is just used as a dispatcher.

Single-step CGI gateways are typically used for quick and relatively simple functions. The two-step CGI gateways are more useful for large, and in many cases, legacy applications. Two-step CGI gateways are commonly used for existing applications with the Web (it is easier to invoke existing programs from CGI scripts than to rewrite them completely as CGI scripts). A combination of both can also be used. Figure 5 shows a CGI-based application.

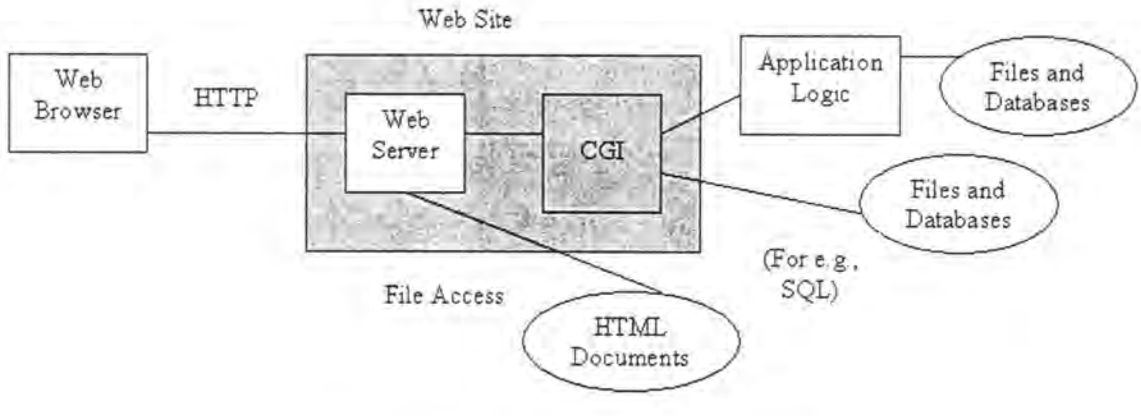

Figure 5: CGI-Based Applications

3.4 Development of Learning Modules

The design and development of learning modules is based on standards and established courseware design principles. The modules are Web-based which means that in order to have access a student needs to have an Internet connection and a Web browser. The learning modules are housed within a virtual learning environment, a server-side software architecture and infrastructure that supports constructivist-learning principles.

The Web server computer has the server software – *Apache* installed on it. The Apache HTTP Server is an open-source HTTP server for modern operating systems including UNIX and Windows NT. It provides a secure, efficient and extensible server that provides HTTP services in sync with the current HTTP standards. This is the program that handles the communication between the client and the server.

The design and development of learning modules is based on standards and established courseware design principles. The modules contain learning materials that would lead students through problem-solving exercises involving real-world watershed management problems and integrate modern technologies to provide a richer vision of complex environmental processes and concepts. Specifically the modules consist of:

- Learning materials (lecture notes) that engage students in active learning about important watershed ecosystem concepts, reinforce scientific methodology, and are vertically scalable.
- A comprehensive digital data library for U.S. watersheds to enhance quantitative reasoning and student driven problem solving.

- Spatially enabled simulation and visualization tools that use watershed digital library to engage students in Geospatial data explorations, modeling and visualization.

3.4.1 Architecture

A mixture of two different but closely related web strategies was used to develop the learning modules. The dissemination of environmental/watershed science education in the form lecture notes / reading material involved just the retrieval and display of the HTML documents that reside on the Web server site. These HTML pages were hyper linked to other Web pages in order to comprehensively cover all the related topics. However, to provide a digital data library for watersheds and to have spatially enabled simulation and visualization tools there was the need to couple the GIS technology with the Internet.

GIS and the Web: The linkage of GIS and Internet technologies is a relatively new area of application development. Although serving static maps has been around since the earliest days of the Internet, it is only recently that interactive maps have been made available on the Web. Web-based GIS may be defined as those technologies that allow the user to interact with data and maps on the Internet. Users are able to determine the variables to be mapped and the type of thematic display, as well as zoom in/out, and identify features on the map (Ralston, 2002).

Web GIS applications involve a user (the client), who contacts a server for some information. The spectrum of strategies used to implement GIS on the Web involves two extremes. The first extreme is for the server to pass data, geoprocessing and mapping application (usually Java applets) to the client. It is known as the "server-supplied" strategy (client-side), which means that the server supplies the data and the programs, but all the GIS functions are carried out on the client side (Figure 6).

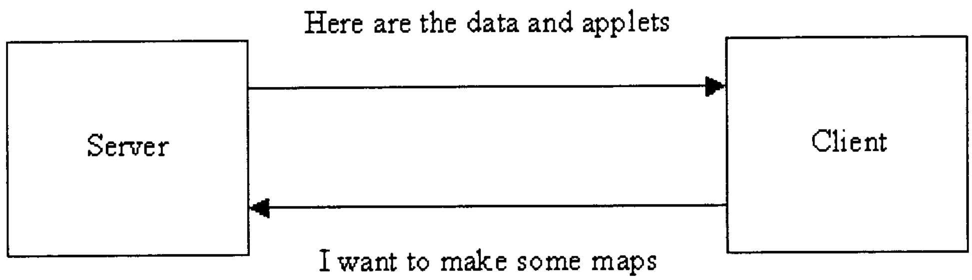

Figure 6: The "Server-Supplied" Strategy

The second strategy called the "client-requested" strategy (server-side) is to have the client indicate the type of map or map function he/she wants to execute, and for the server to pass back the map the client requested (Figure 7).

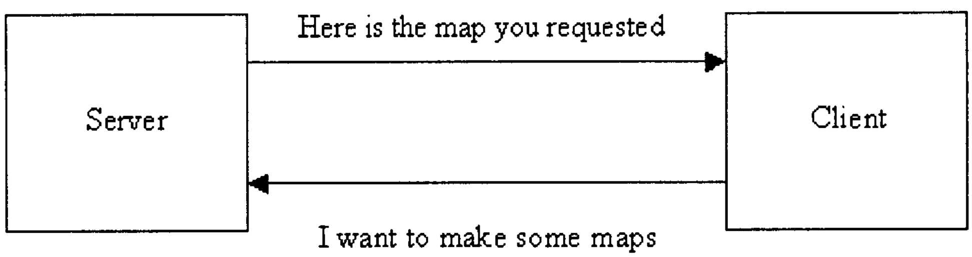

Figure 7: The "Client-Requested" Strategy

"Server-Supplied" Strategy vs. "Client-Requested" Strategy: The right strategy for a given implementation depends on several factors. For the server-supplied strategy the amount of data used in mapping cannot be too large. This type of implementation is unlikely to involve downloading a shape containing 100,000 features, or, even more extreme, large volumes of shape files. The reason for this is that large volumes of shape files will take a long time to transmit and will require the client to have enough disk space and/or RAM to store them. Also in case of sensitive data (like patient records or company sales, etc.) the server-supplied strategy raises unique information security concerns. This raw data could be downloaded from the web site. So in case of large data sets and/or if data security is an issue, the server-supplied strategy should not be used. Another important factor to be considered is that in order to process the data and run the application the client's machine should be capable enough and might require periodic upgrades.

In case of the client-requested strategy, if the site receives a lot of traffic the server could be very busy processing the requests from each user. This could lead to server overload, but the stress on the server can be limited. Some data checking and form processing tasks can be incorporated in the web pages that are to be processed by the client. Table 2 lists the advantages and disadvantages of the server-supplied and the client-requested strategies as described in Marshall (2003).

Based on the issues described above and in order to achieve the research objectives the client-requested (server-side) software architecture was chosen over server-supplied (client-side) software architecture. All the datasets and the programs/functions reside on the server computer. The server can handle requests from multiple clients concurrently and keeps record of each client, processing their requests, and sending back the results.

Table 2: Server-side strategy vs. Client-side strategy

Advantages to Server-Side Web GIS Applications	**Disadvantages to Server-Side Web GIS Applications**
• Simpler to develop	• Primitive Graphical User Interface
• Easier to deploy	• Low graphics quality
• Easier to maintain	• One-click functionality from browser
• Adheres to Internet standards	
• Requires standard Web browser	
• Low bandwidth required	
Advantages to Client-Side Web GIS Applications	**Disadvantages to Client-Side Web GIS Applications**
• Vector data can be used	• Difficult to develop
• Better image quality	• Requires additional software
• Enhanced GUI	• Longer download times
	• No adherence to standards
	• Platform/browser incompatibility

3.4.2 Module One: Basic Concepts of Watersheds

Overview:

This module serves as an introduction to the basic concepts, components and issues associated with watersheds. It provides working definitions of a watershed; the primary ecosystem components that comprise a watershed; why watersheds are important in environmental management; and the local, regional, and national activities that are underway or planned for protecting watersheds and enhancing their structure and functions.

Goal:

The goal of this module is to introduce the concepts of integrated resource management focusing on watersheds. It provides the scientific, technological, and managerial underpinnings necessary for improved understanding of watersheds and the benefits of integrated watershed management.

Learning Objectives:

- Understand the basic principles of watershed management and a watershed management approach
- Understand the basic watershed processes and their interrelated nature
- Know the concepts of watersheds, ecosystem management, and cumulative impact assessment
- Understand the strategies and responses to watershed management problems
- Understand the elements of a successful watershed management framework
- Understand the benefits of a watershed management approach

Topics Covered:

- What is a watershed?
- Why a watershed approach?
- Advantages and impediments of a watershed approach
- Watershed response and human activities
- Functional elements of a watershed

- Watershed analysis and planning
- Community-based management approach
- Tools for watershed management
- Historical perspectives of watershed management

3.4.3 Module Two: Introduction to Watershed Ecology

Overview:

This module concentrates on providing improved understanding of watershed structure and how human activities can degrade or improve the integrity and functioning of watersheds. This module also discusses the major biotic and abiotic components of watersheds, natural processes, interrelationships occurring in watersheds, and the spatio-temporal aspects of watershed management. Understanding watershed structure and the natural processes is crucial to grasping how human activities or human-induced anthropogenic stresses can degrade or improve the condition of a watershed. Knowing these watershed structural and functional characteristics and how humans influence them is prerequisite to effective watershed management.

Goal:

The goal of this module is to introduce the terms and concepts associated with watershed ecology, describe the structure and functioning of watersheds, enhance the scientific understanding of the relationship between biotic and abiotic components of watersheds, and provide examples of contemporary issues in watershed ecology.

Learning Objectives:

- Know the biotic and abiotic components of watersheds
- Understand the basic natural and human induced processes and phenomena occurring in watersheds
- Understand how watershed structure and functions change in space and time
- Suggest a wide variety of novel approaches for managing anthropogenic watershed landscapes

Topics Covered:

- Defining watershed landscapes and processes
  - Watershed forcing functions
  - Hydrology
  - Climate/Meteorology
  - Geomorphology
- Biophysical components of watersheds
- Watershed Biogeochemistry
- Natural Systems Concept of Watershed Ecology
- Watershed Eco-structure and function
- Biological Indicators of Watershed health

3.4.4 Module Three: Principles of Watershed Hydrology

Overview:

Hydrology is an interdisciplinary earth science that is concerned with the movement and occurrence of water on earth. Water is our most critical resource. Thus, hydrology is significant as both a science and engineering discipline. This module covers the concepts and principles of watershed hydrology and surface hydrologic phenomena including precipitation, evapotranspiration, stream flow, snow and snowmelt, and rainfall-runoff relations. Also this module introduces the components of the hydrologic cycle from a watershed perspective. Multimedia, simulation, and visualization tools, together with the watershed digital library, provide critical-thinking and problem-solving exercises. The geographic (spatial) aspects of environmental hydrologic processes are enforced through simulations and comparison of data for typical watershed.

Goal:

The overarching goal of this module is to improve the understanding of watershed hydrological processes, concepts and principles.

Learning Objectives:

- Understand the physical processes involved in the transfer of water between the various reservoirs (pools) of the hydrologic cycle at local and global scales
- Understand the interdisciplinary nature of hydrology, and the role that water plays in linking the physical, biological, and atmospheric systems
- Apply knowledge of physical processes to solving society's water resource problems
- Be able to quantify the basic hydrologic processes occurring on watersheds

- Know how to integrate spatial and non-spatial data, simulation models, geospatial technologies, and visualization tools to address watershed hydrological issues

Topics Covered:

- Introduction to watershed hydrology
- Introduction to the hydrologic cycle
- Components of the hydrologic cycle
  - Precipitation
  - Evaporation and evapotranspiration
  - Storage and groundwater flow
  - Runoff / Overland flow and stream flow
- Erosion and sedimentation
- Snow accumulation, melt, and vaporization
- Energy exchange
- Soil moisture movement and storage
- Water balance computation
  - Global water and energy balance
  - Watershed mass balance
  - Water balance models
- Watershed Hydrologic models

3.4.5 Module Four: Watershed System Dynamics

Overview:

Understanding watershed structure and natural processes is critical to understanding how human activities can degrade or improve the conditions of the watershed, including its water quality, its wildlife and aquatic species, its forests and vegetation, and the quality of community life for people who reside there. Understanding watershed dynamics, structure, and functioning and how human influence sets the stage for effective watershed management. This module provides a systems approach to the management of watersheds and examines the interrelationships between different watershed processes and phenomena. Information is provided to improve the understanding of the biogeochemical cycling in a watershed as well as enhance the knowledge of watershed system inputs, interactions, and outputs.

Goal:

The primary goal of this module is to introduce the concepts associated with watershed ecology, by exploring watershed systems dynamics. The biogeochemical cycling of materials with a watershed provides pertinent information on the biotic components.

Learning Objectives:

- Know the basic biotic and abiotic components of watersheds and the basic natural and anthropogenic processes occurring within the watershed
- Understand how watershed structure and functions may vary in space and time
- Understand the interrelationships between watershed physical, biological, chemical, and, geological processes and their human components.

Topics Covered:

- Introduction to watershed ecology
- Watershed Physical Processes
- Watershed Biochemistry - Nutrient Pools and Processes
- Elemental flux in the watershed environment
- Natural systems concepts
- Watershed Biological Settings
- Watershed structure
- Watershed functioning
- Human dimensions of watershed management
- Watershed risk assessment

3.4.6 Module Five: Watershed Data Management

Overview:

Like its ecological counterparts, watershed ecology has experienced a computational revolution during the past decade or so. During this period, we have seen computers shrink from room-size mainframes that required keypunched computer cards for data inputs, to the powerful, small-footprint PCs that occupy today's desktops, and, to powerful wireless speech based personal digital assistants and thin clients. Early data management was relatively straightforward, consisting of color-coded card decks and the occasional rubber band for "large" data sets. The advent of the calculator enabled ecologists to hand-compute solutions to regression equations; map overlay provided the technique to deriving watershed thematic maps; and quality assurance meant punching everything twice until identical answers were obtained. Today, technological advancements in computing, information/data management, and telecommunications have brought new excitement to watershed managers and scientists. New sensors, data collection and storage devices, sophisticated analytical and statistical methods, and geospatial technologies (e.g., geographic information system, global positioning satellite systems, and, remote sensing systems) provide us with an enormously powerful toolkit to address extremely complex, challenging, and socially important watershed management questions. Recent advances in database concepts, including data warehousing, client-server architectures, and data mining have also ushered a new era for the management of watershed data. This module will provide a concise, rigorous, and in-depth treatment of watershed data characteristics and the tools for data analysis and visualization. It will introduce the concepts of databases and database management systems, as well as the use of GIS in watershed management programs. The objective of this module is not to duplicate any existing materials on geographic (spatial) databases, but rather to utilize several case studies and exercises to enhance understanding of the role of emerging Geospatial technologies in watershed management and planning.

Goal:

The overarching goal of this module is to present the concepts and principles of watershed database acquisition, and, management.

Learning Objectives:

- Understand the characteristics of watershed data, specify the characteristics of watershed digital data needed to perform common management tasks
- Understand the source and content of watershed digital and nondigital data
- Understand the principles of geographic data (e.g., data models, map projections) and their connection to watershed management
- Develop a small spatial database for a watershed management project
- Locate various spatial data sources over the Internet.

Topics Covered:

- Basic concepts of watershed data management
- Fundamental concepts of watershed data management
  - Introduction to spatial and non-spatial data management
- Spatial/Non spatial representation of watershed features
  - Representation of the spatial domain
  - Watershed features representation in GIS
  - Attributes of watershed features
- Developing Digital (Spatial/Attribute) databases for watersheds
  - Spatial data sources and data formats
  - Spatial database design
- Watershed data types and sources

- Socioeconomic data (demographic, economic, social, legal, financial)

- Physical data (land resource, geology, hydrology, metrology, water quality)

➢ Properties of watershed data

- Metadata

- Entities and attributes

- Spatial data organization

- Spatial reference systems

- Watershed data quality

➢ Map scale and projections

- Map scale

- Map projection

- Coordinate transformations

- Georegistration

➢ Exploring Watershed data

- Global positioning systems

- Aerial photography

- Census/Socioeconomic

➢ Nature of Watershed data

- Data, information, and, information systems

- Databases and database management

- Data models

- Data integration

- Design of watershed spatial data

➢ Spatial data sources and data formats

- Available spatial data formats

- Watershed data

- River data

- Land cover and Land use

- Census data

- Climate data

- Surface water quantity data

- Water quality data

- Global data

3.4.7 Module Six: Watershed Modeling for Management and Planning

Overview:

The two overreaching goals of a sustainable watershed management are (a) understanding the physical, chemical, and biological processes in natural resource systems; and (b) developing tools that allow decision makers and watershed stakeholders to make use of that understanding to improve management. The overall goal of linking the understanding to decision-making tools is usually achieved using computer simulation models that encapsulate the knowledge in the form useful to managers. Watershed simulation models are particularly important in integrating science and management of watersheds in an interactive manner. In addition to these roles, watershed simulation models provide the mathematical framework for integrating the physical, chemical, and, biological processes occurring in a watershed ecosystem. In this module, the features, characteristics of modules, and their roles in watershed management and decision-making are explored.

Goal:

The overreaching goal of this module is to provide a concise treatment of computer simulation models used for watershed management and planning focusing on those models that integrate the physical, biological, chemical and societal factors that impact watersheds as well as those that address complex environmental and water resource problems.

Learning Objectives:

- Understand the philosophical and scientific principles of watershed modeling and the functional classification of models
- Know the methods for establishing model reliability and quality assurance
- Understand the spatial and temporal classification of models
- Understand the concepts of lumped and distributed-parameter models

- Know the functional components, characteristics, strengths, weaknesses and modes of application of many hydrologic and water quality models
- Understand how to develop and apply a watershed model
- Know how to link real-world data with geospatial tools such as GIS to explore watershed management problems

Topics Covered:

- Introduction to watershed modeling
  - What are models?
  - Functional classification of models
  - Assessing model reliability and quality assurance
- Characteristics of lumped-parameter models
  - Process-level review of lumped models
  - Strengths and weaknesses of lumped models
  - Parameters assessment and data inputs for lumped models
  - Evaluating reliability of lumped models
- Characteristics of distributed-parameters models
  - Process level review of distributed models
  - Strengths and weaknesses of distributed watershed models
  - Evaluating reliability of distributed models

- Watershed Modeling Interfaces and Environments

3.4.8 Module Seven: Nonpoint Source Pollution Control in Watersheds

Overview:

In the United States, as well as in many developed and developing countries, the contamination of land, water, and air continues to be an important environmental problem. Despite significant strides made in the United States to control pollution from point sources, nonpoint pollution continues to be the major source of environmental degradation. Nonpoint source pollution remains the nation's largest source of water quality problems. It is the main reason that approximately 40% of surveyed rivers, lakes, and estuaries are not meeting basic uses such as fishing, and, swimming. Agriculture, forestry, grazing, septic systems, recreational boating, urban runoff, construction, physical changes to stream channels, habitat degradation, and many other forms of human activities are all sources of nonpoint pollution. The most common nonpoint pollutants are sediment and nutrients. Other pollutants derived from nonpoint (diffuse) sources include pesticides, pathogens (bacteria and viruses), salts, oil and grease, toxic chemicals, and heavy metals. Atmospheric deposition and hydro-modification are also sources of nonpoint source pollution. This module introduces the concepts, principles, and issues of non point source pollution in watersheds. The focus is on the relationships between human activities within a watershed and the hydrologic and water quality response. The module also discusses the concepts of nonpoint source pollution and explores the cumulative impact of land use, best management practices, landscape reconfiguration and other management strategies on water resources.

Goal:

The primary goal of this module is to introduce the concepts, principles, and issues of nonpoint source pollution in watersheds and the techniques, tools, and, methods for controlling the pollution problems.

Learning Objectives:

- Understand the causes, sources, and extent of the nonpoint source pollution problem
- Understand the methods, tools, and techniques for assessing the extent and magnitude of the nonpoint pollution problem in rural and urban watersheds
- Be able to utilize various computer-based tools (models, visualization, geospatial) to evaluate the magnitude and scale of watershed nonpoint source pollution
- Understand the policy, institutional, and organizational factors associated with nonpoint source pollution
- Understand the different options for controlling nonpoint source pollution
- Understand the applicability and limitations of models and other tools for managing the nonpoint source pollution problem in watersheds
- Be able to specify management measures for controlling the nonpoint source pollution problem
- Describe and discuss state and federal regulations that influence nonpoint source pollution

Topics Covered:

- Introduction to nonpoint source pollution
  - Sources and magnitude of nonpoint source pollution
  - Nature of urban and agricultural nonpoint source pollution
  - Preventive measures for nonpoint source pollution
  - Policy and institutional options for nonpoint source pollution control
  - Community-based approach to nonpoint source control in watersheds
- Methods for assessing nonpoint source pollution
  - Watershed monitoring concepts, design and implementation
  - Watershed monitoring data assessment and reporting
  - Watershed monitoring data and information management
  - Principles of watershed modeling for nonpoint source pollution control
- Watershed Nonpoint Source Problem Analysis
  - Case study One: Assessing critical areas of watershed land use inputs
  - Case study Two: Nonpoint Source Pollution and TMDLs
  - Case study Three: Evaluating impacts of chemical management.
  - Case study Four: Watershed management in the urban environment.

3.4.9 Module Eight: Digital Data Library

Overview:

Digital libraries linked by the Internet are evolving quite rapidly into a body of knowledge on almost all aspects of society, and many digital libraries contain large volumes of data describing the state of the environment. Today, disparate resource management data can be accessed and used in creating digital representations of almost any terrestrial phenomenon and at user-defined spatial and temporal scales. Furthermore, digital library environments that not only support course archiving, instantiation, and presentation, but also provide student-centered active learning mechanisms have proliferated during the last decade. Progressive watershed education requires students to be involved in active, collaborative learning using large amounts of data and analytical tools.

Goal:

The goal of this module is to provide a watershed digital data library that would be a test bed consisting of comprehensive, diverse spatial/nonspatial and temporal data and tools that can be used for effective watershed ecosystem management and planning. The architecture of the digital library consists of four relatively simple components, namely, a user interface system, a data catalogue system, a storage/retrieval system, and a display system, all couched within standard client-server paradigms. Core data holdings include typical data collected on watersheds such as meteorological, topographical, hydrologic, soils, land use, vegetation, and land management.

3.4.10 Module Nine: Simulation and Visualization

Overview:

Cognitive research on how students learn earth and environmental science repeatedly shows that the large achievement gains result when students are active participants in the learning process (Linn and Songer 1993). However, providing students with opportunities to be active learners is a formidable challenge in the context of undergraduate lecture courses that use traditional learning paradigms. This module provides web-based online simulation and visualization tools that allow for deterministic, process-based watershed modeling and integrate it with VRML, a standard language for describing interactive 3D objects and worlds delivered across the Internet, and the watershed digital data library described earlier. This pedagogical element presents spatially complex, time-dependent environmental phenomenon such as NPS pollution from agricultural management to the student as 3D animations that the student users can view form different perspectives.

Goal:

The goal of this project is to allow the students to select a watershed and watershed management problem (e.g., water quality), generate and assemble data for the watershed, model and study it, and examine, display, and visualize the results, all within the Web environment. This module will provide faculty and students, as well as resource managers, with the tools to explore multidimensional environmental processes through the Internet.

3.4.11 Module Ten: Laboratory Exercises

Overview:

In this module a set of lab exercises have been provided which have been designed to teach the students to use ESRI's ArcGIS software and how to use it in natural resource management. Within each exercise a problem has been provided, to allow the students to relate the techniques that the exercises teach to real-world situations. A brief description of the different exercises is given below.

Laboratory Exercise 1: Working with Data Frames – This is an introductory exercise and the aim is to make the students familiar with the ArcMap interface. The exercise explains the various toolbars on the interface and also has a brief description of some common terms used with respect to ArcView.

Laboratory Exercise 2: Creating Spatial Data – This exercise teaches ways to create spatial data in ArcView using, for example, another layer as a backdrop for "heads-up digitizing". The aim is to help the students understand the process, and provide some idea of the time commitment involved in creating spatial data.

Laboratory Exercise 3: Editing Spatial Data – This exercise teaches the students to edit existing shapefiles and creating new shapefiles. The aim is to make the students aware of the various issues related to editing like creating and/or maintaining topology. A description of the tools available for editing has been provided.

Laboratory Exercise 4: Manipulating Attribute Tables I – In GIS, non spatial data of geographic features are stored in attribute tables. In ArcView GIS, tabular data can be easily manipulated. This exercise teaches, for instance, how to create a new table by importing data, adding fields and records to an existing table, editing values of an existing table, or exporting data to create a new table.

Laboratory Exercise 5: Manipulating Attribute Tables II – This exercise is an extension to the previous one and covers some advanced issues like joining, relating, and hyperlinking related to attribute data management.

Laboratory Exercise 6: Geocoding, Map Projections and Coordinate Systems – In general terms, geocoding is the conversion of spatial information into computer readable form. This exercise deals with the processes and concepts of this conversion. Map projections and different coordinate systems are also explored.

Laboratory Exercise 7: Analyses on Vector Data I – A fundamental component of GIS is its ability to support spatial analysis to uncover both obvious and hidden relationships in the data. This exercise deals with the simple spatial analyses operations summarization, selection of features based on their relationships with other features, buffering, and performing spatial joins.

Laboratory Exercise 8: Analyses on Vector Data II – This is a follow up exercise to the previous one and the aim is to move beyond the basic analysis functions provided in ArcMap. This exercise exposes the software's total functionality including the advanced geoprocessing tools and utilities.

Laboratory Exercise 9: Analyses on Raster Data – There are two primary data structures used in a typical GIS: vector and raster. The emphasis of this exercise will be on working with raster data. Various spatial analysis capabilities of ArcView with respect to raster data like interpolation, surface analysis, distance functions, and raster calculation are covered.

Laboratory Exercise 10: GPS and ArcView – This exercise teaches the students the technique of importing the data collected using GPS into ArcView for performing further analyses.

CHAPTER 4. EXAMPLE APPLICATION

The range of potential applications of a collaborative virtual learning environment is large and varied. One of the many scenarios exemplifying this range involves environmental/ecological science education focusing on watersheds. In line with the importance of learning and with our goal of improving undergraduate education in agriculture and environmental science disciplines, a scenario involving learning at the undergraduate level is presented. Assume that the learning activities of an upper-level undergraduate course in, for example, environmental management for natural resource conservation involve: 1) sessions in which an instructor presents relevant information to students; 2) collaborative learning activities in which small groups of students investigate specific problems in watershed management, for example, nonpoint pollution control; and 3) individual students study sessions. Similar scenarios could be constructed for disciplines in the biological, ecological, and natural science disciplines.

The instructor uses the services of the learning environment to examine and utilize information resources for class presentations, laboratory sessions, and interactions with students. For presentations on watershed management, for example, the instructor engages the services of the digital library for discovering information resources for display during class presentations that includes images, videos, datasets, and simulation models. The digital library responds iteratively to the instructor's request by 1) discovering appropriate correlations of heterogeneous information on watersheds and meta-information resources, 2) constructing additional meta-information that describes the semantic relationship between datasets and analytical tools. The instructor uses the services of the digital library to examine maps on which icons indicate availability of different information resources and modeling procedures. During class presentations, the instructor accesses the services enabling the visualization of data – basic or derived, in a flexible manner. In response to questions about different "what-if " simulation scenarios of land uses, the instructor can display the simulation modeling results characterized by datasets compatible with the input requirements of a simulation model, and runs the model by dragging and dropping the constituted datasets onto its icon.

The students, in collaborative study groups, use the environment to reach informed decisions about managing environmental resources. In evaluating implications of watershed management systems, for example, groups of students can utilize the services provided by the virtual learning environment to: 1) discover and integrate disparate information resources, related human activities and their effects on watersheds; 2) access, visualize and evaluate relevant information resources for understanding the human and societal implications of watershed management; and 3) simulate and evaluate alternative strategies in terms of their net environmental benefits.

4.1 Example Application of use of the Learning Environment

In order to understand how the virtual learning environment would be beneficial to the students and would promote constructivist learning in watershed/environmental science, an example exercise is illustrated in this section.

4.1.1 Objective

The primary goal of this exercise is to enable the students to improve their understanding of nonpoint source pollution problems associated with agricultural use of pesticides in watersheds and to allow them to interact with the hydrologic as well as the various geographic datasets. The tasks that the students would be engaged in range from collection and preprocessing of the relevant datasets to the running of a model that simulates transport and fate of agricultural pesticides within watersheds. Pertinent modeling equations have been embedded within a GIS to enable the students to carry out spatio-temporal analyses on the movement and fate of a pesticide. Also once the students have obtained the results, they can perform various "what-if" analyses by changing the inputs to the simulation model. This would not only allow the students to determine the different factors and the magnitude of their influence on chemical concentrations in, for example, surface runoff, but will also provide them an interactive, integrative environment to explore the effectiveness of various management practices to reduce the chemical losses. Through this process, students are able to improve their environmental decision making capabilities, utilize critical data inputs representing the landscape and biophysical processes, and explore the efficacy (social and ecological) of alternative strategies and policies.

4.1.2 Modeling of Pesticide Transport in Surface Runoff

For each runoff event, certain amount of pesticide is lost in runoff and sediment in the runoff. In representing the processes that occur during a precipitation-runoff event, mathematical expressions are needed to describe the mass balance of a pesticide in the top 1 cm of soil, the mass transfer of pesticide into runoff, and the pesticide concentration in the runoff and in eroded soil particles. Pesticide degradation during transport is assumed to be negligible. In general, the total pesticide loss for each runoff event decreases with time and is strongly correlated with the total amount of pesticide remaining in the runoff active zone (0-1 cm depth) of the soil surface. Thus, the pesticide losses in runoff are dependent upon the "available" amount of pesticide in the surface soil and the amount applied to control weeds or pests. These losses, in turn, are determined by the persistence, retention, and mobility of the pesticide.

In this research, the model described by Haith (1980) was used to estimate pesticide losses in runoff. A mass balance of pesticide in the top 1 cm of soil formed the basis of the model. It is assumed that the pesticide mass, which percolates below this soil depth, is not available for runoff. The assumption of 1 cm depth is an arbitrary cutoff point in this study. Many researchers believe this depth to be reasonable estimate of the active runoff zone (Donigian and Crawford, 1976; Rao, 1982; Rhode et al., 1980).

Pesticides in the soil are assumed to decay exponentially with time. If a precipitation-runoff event occurs t days after application, the pesticide mass in the top surface soil layer is given by:

[1] $$P_t = P_o \exp(-\alpha t)$$

in which P_t is the pesticide mass in the surface soil (kg/ha); Po is the initial pesticide content of the top surface soil layer immediately after application (kg/ha), usually the application rate; α is the pesticide decay rate (day-1), which can be expressed as:

$$\alpha = 0.693 / t_{1/2}$$

where $t_{1/2}$ is the half-life (day) of the applied pesticide.

The total pesticide available for runoff (P_t) can be divided as follows:

[2] $$P_t = P_s + P_w$$

where P_s and P_w are the potentially available adsorbed-phase and dissolved-phase pesticide levels, respectively.

Adsorbed-phase pesticide loss

The potentially available pesticide level in the adsorbed phase, P_s (kg/ha), can be obtained by using the expression:

[3] $$P_s = P_t / (1 + \theta / K_d\, \rho)$$

in which θ is the volumetric available water (cm/cm), ρ is soil bulk density (g/cm3), and K_d is the adsorption partition coefficient (cm3/g), which can be expressed as:

[4] $$K_d = K_{oc} * f_{oc}$$

where K_{oc} is organic carbon partition coefficient (cm3/g) and f_{oc} is soil organic carbon fraction.

Thus, the actual adsorbed-phase pesticide loss in runoff, P_{rs} (kg/ha) can be calculated by:

[5] $$P_{rs} = (A_s / 100 * \rho) * P_s$$

where A_s is the soil loss, which can be obtained by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978).

[6] $$A_s = R*K*LS*C*P$$

in which R is rainfall runoff factor; K is soil erodibility factor; LS is topographic factor; C is management and cropping factor; and P is conservation practice factor.

Dissolved-phase pesticide loss

Pesticide in the dissolved phase of the top soil is a function of soil water content. For runoff-producing event (represented with total precipitation ***P***), the potentially available pesticide in the dissolved phase, P_w (kg/ha), can be expressed as:

[7] $$P_w = P_t / (1 + (K_d \rho / \theta))$$

Neglecting volatilization losses, the dissolved-phase pesticide can fall into one of the three primary pathways: the surface soil runoff, percolate deeper into the soil profile, or remain in the top surface soil layer. It is assumed that these three pathways are proportional to the distribution of rainfall (***P***) into runoff (***Q***), percolation ($P-Q-\theta$), and available soil water (θ). Then, the actual dissolved phase pesticides loss in runoff water, P_{rw} (kg/ha), becomes:

[8] $$P_{rw} = (Q / P) * P_w$$

The total pesticide remaining in the top soil layer, P_{total} (kg/ha), after the rainstorm is:

[9] $$P_{total} = P_t - P_{rs} - (1 - \theta / P)\, P_w$$

The Soil Conservation Service (SCS) curve number model described in the Technical Release SS (U.S. Soil Conservation Service, 1986) was used to estimate surface runoff from a land element. Thus, runoff volume ***Q*** is:

[10] $$Q = (P + SM - 0.2S)^2 / (P + SM + 0.8S)$$

in which ***P*** is the rainfall amount (cm), ***SM*** is the snowmelt water, and ***S*** is soil-water storage potential (cm) given by:

[11] $$S = 2.54\,[\,(1000 / CN) - 10\,]$$

where ***CN*** is SCS curve number dependent on the antecedent moisture condition.

4.1.3 Study Area: Squaw Creek Watershed

The Squaw Creek watershed is located in Story, Boone, and Hamilton Counties in central Iowa. It is typical of watersheds that lie in recently glaciated agricultural landscapes of central Iowa and the Midwest (Prior, 1991). The watershed is part of a larger river basin, the Skunk River Basin, covering 11280 km^2, which extends southeastward to the Mississippi River. The Squaw Creek drainage area is small, covering approximately 563 km^2. It has a narrow floodplain of about 0.5 km wide, which provides little storage capacity for flood waters (Snyder & Associates Inc., 1996). The main channel is about 53 km in length. Squaw Creek is a third-order stream and drains level to gently undulating topography before emptying into South Skunk River. Average channel slope is about 1.7 m/km (Slack et al., 1993). The creek begins in southwestern Hamilton county, flows through northeastern Boone county and northeastern Story county before reaching the South Skunk River. Main tributaries to Squaw Creek include from north to south, Crooked Creek, Montgomery, Creek, Lyndis Creek, Onion Creek, Clear Creek, College Creek, and Worrell Creek (Jeanne, 1998).

Most of the area was originally covered by a continuous mosaic of prairies, forests and wetlands (Thompson, 1992). These ecosystems provided a natural equilibrium for the water cycle, with extensive areas of high infiltration resulting low runoff (Anderson et al., 1996). After the arrival of Euro-American settlers in the mid-1800s, the original landscape was, for more than 90%, gradually converted into agricultural and urban uses. Nowadays, most of the area in Squaw Creek is in cultivation, with corn and soybeans being the major crops (Andrew and Dideriksen, 1981; DeWitt, 1984; Dideriksen, 1986). Smaller acreages of pastures, oats, hay and woodland are found as well. A small urban area is present in the basin: the city of Ames located at the confluence of Squaw Creek with the South Skunk River, and comprising approximately 6 km of reach on Squaw Creek. Other smaller communities are Stratford and Stanhope located in the northern portion of the basin, and Gilbert in the southeastern portion (Jeanne, 1998).

The predominantly agricultural landscape is due to the fact that soils are particularly fertile in this part of the state. The major soil associations in the Squaw Creek watershed are the Clarion – Webster-Nicolett, Clarion-Storden-Coland, Hayden-Lester-Storden, Colden-Spilville-Zook and Canisteo-Okoboji-Nicolett (Glanville, 1987). Low elevations and a moderate relief characterize these soil groups. Because many soils are poorly drained and many wetlands represented an obstacle to cultivation and grazing, an extensive, yet unmapped, tile drainage system has been established. The presence of such subsurface drainage systems probably did impact the overall runoff potential within the basin and increased the flood hazard. In addition channelization and excavation of drainage ditches have sped up the movement of water and created deeply incised channels with unstable banks. Modern agriculture has thus accelerated the streamflow of agriculture in the landscape and made the area more prone to flooding.

Soil survey data (Andrews and Diderikersen1981; DeWitt, 1984; Diderikersen1986) and USGS water reports (Slack et al., 1993) indicate that the average annual precipitation over the basin is approximately 81 cm. Of this, about 75 % usually falls between April and September. Precipitation early in spring in conjunction with snowmelt can create favorable flooding conditions.

4.1.4 Using the Virtual Environment for Modeling Pesticide Loss from a Watershed

A simplified geospatial nonpoint source-modeling environment was developed using ESRI's ArcGIS software package. A special program written in Visual Basic and ESRI's ArcObjects was used to completely incorporate modeling equations within the GIS. ESRI® ArcObjects™ is the development platform for the ArcGIS™ family of applications such as ArcMap™, ArcCatalog™, and ArcScene™. The ArcObject's software components expose the full range of functionality available in ArcInfo™ and ArcView® to software developers. ArcObjects is a framework that allows users to create domain-specific components from other components. It provides an infrastructure for application customization.

The environment consists of four main sub systems namely the GeoSpatial Data Processing System, the Curve Number Generator, the Soil Loss Calculator and the Pesticide Loss Calculator. The idea of modeling NPS pollution for an entire watershed is from distributed model, which intends to divide the study area into uniform grid cell and to perform the modeling process for each individual cell. As the cell size decreases, the information extracted from the original data would be more realistic than lumped model, which would aggregate information and use only one value to represent the entire study area. For this purpose raster grids have been used as inputs to the modeling system. When the model is run, it generates three new grids on the fly, which have the curve number, soil loss, and the pesticide loss values for the entire watershed. These new grids have similar cell resolution and spatial reference as the input grids to the system.

This section describes the way these subsystems can be used to determine the pesticide losses and perform various "what-if" analyses on the Squaw Creek watershed. First the data sets are processed using the Geospatial Data Processing System and then these geoprocessed datasets are passed as inputs to the other three subsystems in order to derive the final results.

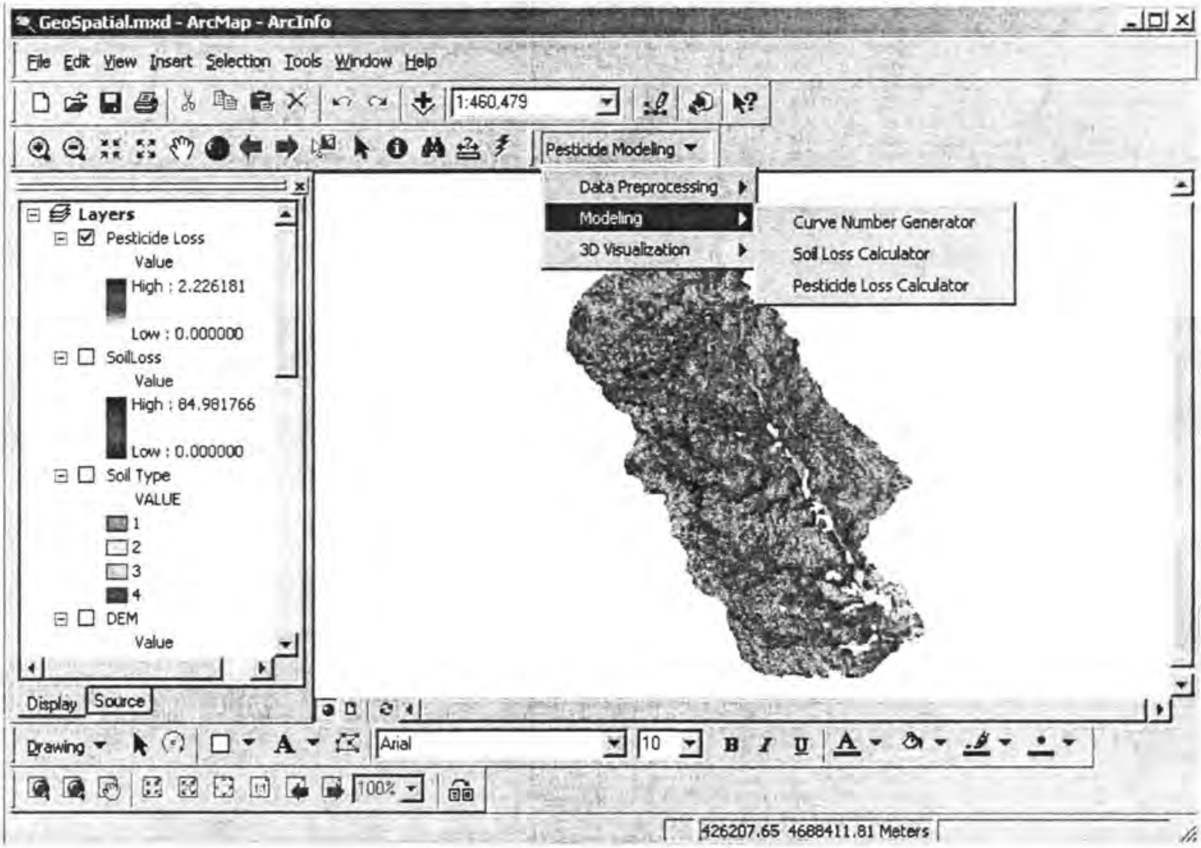

Figure 8: Geospatial Nonpoint Source-Modeling Environment

4.1.4.1 Data Acquisition and Preprocessing

The primary data sets, which were of importance in the study, were the topographic data, land use/ land cover, soils and rainfall data. The topographic data was obtained from the GIS lab at Iowa State University. The topographic data was a DEM of 30*30 m relation at a 1:250,000 scale for the state of Iowa. The land use/land cover data was obtained from the Natural Resources GIS Library through the Iowa Department of Natural Resources (http://www.igsb.uiowa.edu/nrgis/gishome.htm) and the soils data was obtained from the Soil

Survey Geographic Database (SSURGO), which is available for download for selected Iowa Counties (http://www.ftw.nrcs.usda.gov/ssur_data.html). SSURGO is the most detailed level of soil mapping produced by the USDA Natural Resources Conservation Service (NRCS).

As the area covered by the Squaw Creek watershed falls in more than one county, so the first geo-processing operation performed was to merge the corresponding datasets for all the counties. The merging operation gave as output a new datasets, which had the features as well as the specified attribute information from the individual datasets for all the counties. Next the merged datasets were clipped to the boundary of the watershed. The merging and clipping operations were done by using the Geoprocessing Wizard (Figure 9) in ArcMap. The next step, which involved all the datasets, was reading the metadata of all the datasets and making sure that, all the datasets were in the same projection system. This was done using ArcToolbox application of ArcView GIS. All the data sets used in this study were stored in the Universal Transverse Mercator projection system. After this all the shapefiles for the watershed were converted to raster grids with the same cell resolution (30*30m) as that of the DEM for the watershed by using the Spatial Analyst extension of ArcView GIS. Finally the datasets were stored in a database created for the watershed and used, as required, in the procedure described below.

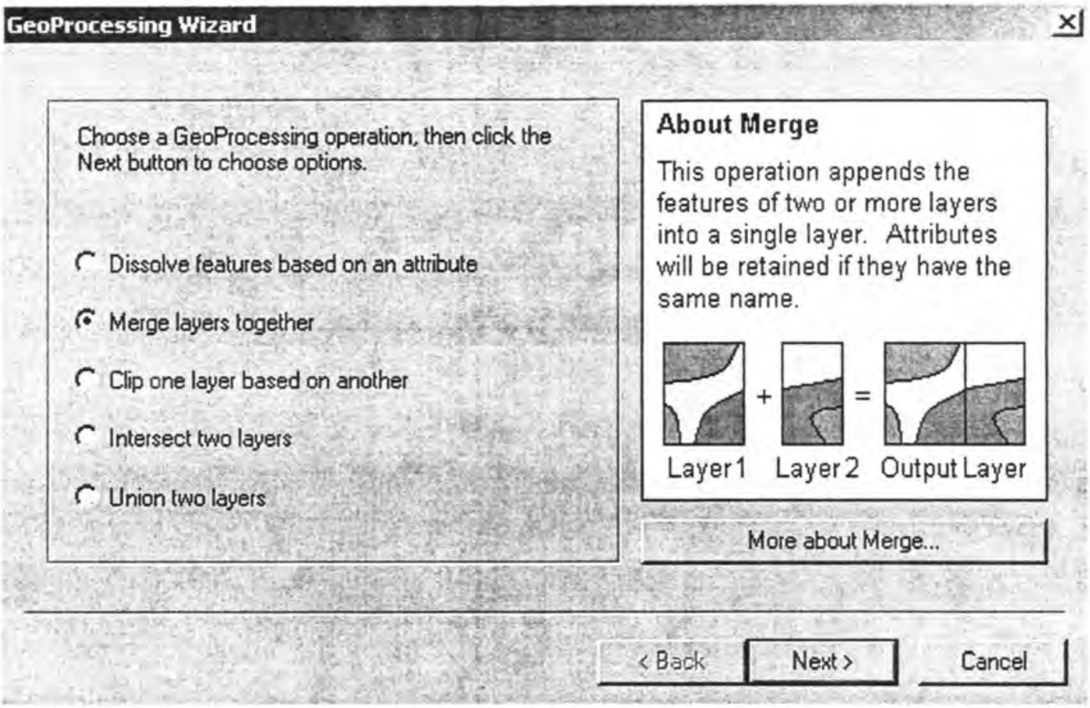

Figure 9: GeoProcessing Wizard from ArcMap

4.1.4.2 Curve Number Generator

The Curve Number Generator (Figure 10) was developed as an addition to the core ArcMap interface. A new toolbar named "Pesticide Modeling" was created and added to the ArcMap interface. The Curve Number Generator was made accessible from ArcMap through a button attached to the "Pesticide Modeling" toolbar.

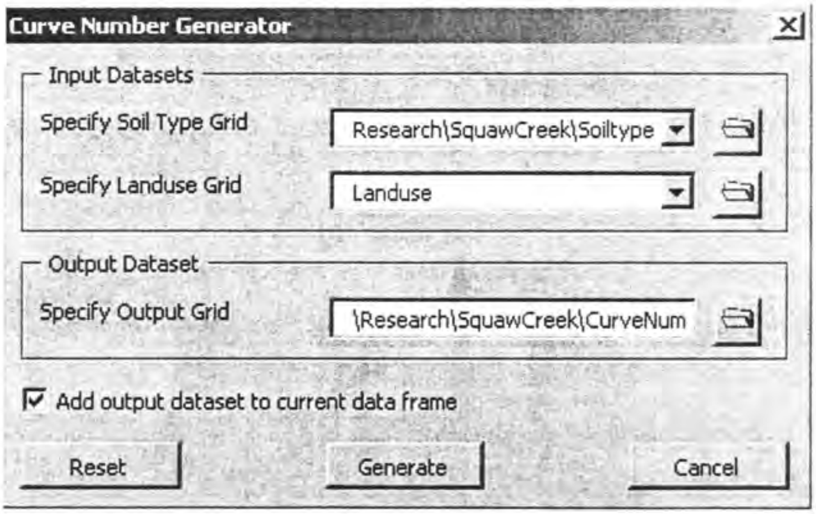

Figure 10: Curve Number Generator

The Curve Number Generator takes the soils and the land cover grids as the primary inputs. The output is a grid, each cell of which contains the curve number for the area that it represents (Figure 11). A further extension to this interface is the rainfall-runoff calculator in which students can input the precipitation amount to generate a grid, each cell of which has a value equal to the amount of runoff from that area. The students can make use of this utility to experiment with the change in the precipitation-runoff with the change in the land use of an area.

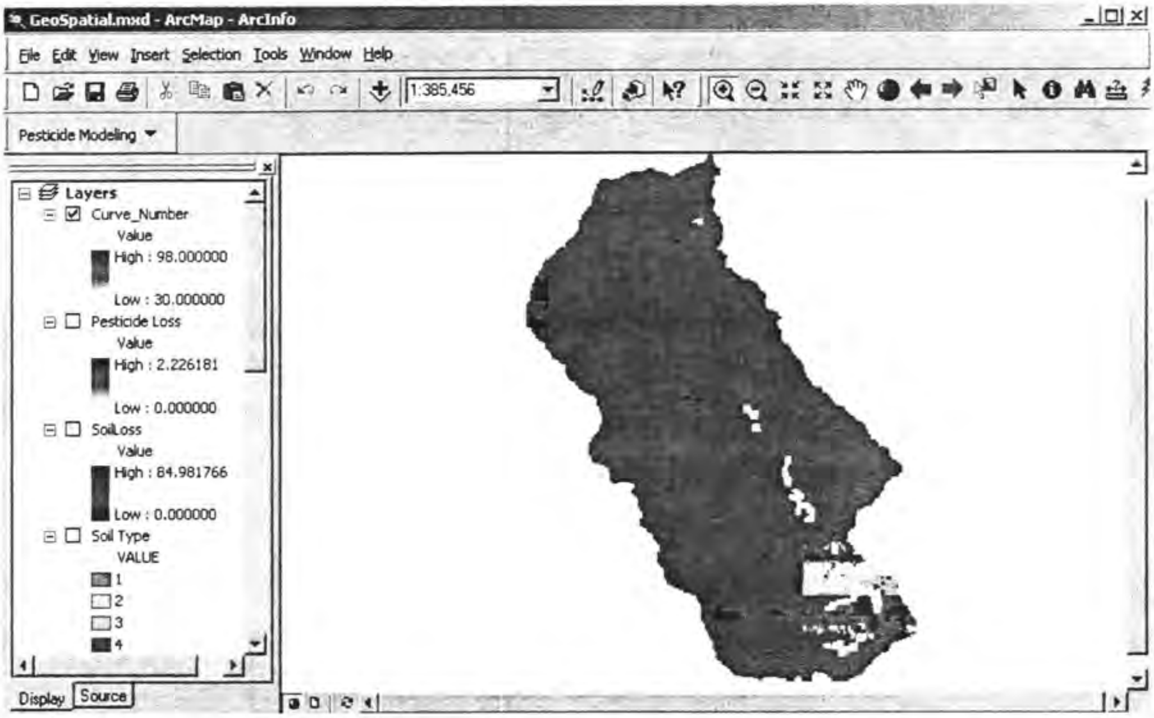

Figure 11: Curve Number Grid of Squaw Creek Watershed

4.1.4.3 Soil Loss Calculator (USLE)

The third step in the pesticide modeling process is deriving the soil loss grid. This can be accomplished by using the Soil Loss Calculator (Figure 12), which was developed using Visual Basic and ArcObjects. This calculator is accessible through a button on the "Pesticide Modeling" toolbar on the ArcMap interface. It takes as input the digital elevation model (**DEM**), the soil erodibility factor (**K**) grid, the crop type factor (**C**) grid, the rainfall runoff factor (**R**) and the support factor (**P**) values for the study area. This calculator is based on the Universal Soil Loss Equation (USLE), which gives the soil loss in tons per acre per year as:

$$\textbf{Soil Loss} = \mathbf{R*K*LS*C*P}$$

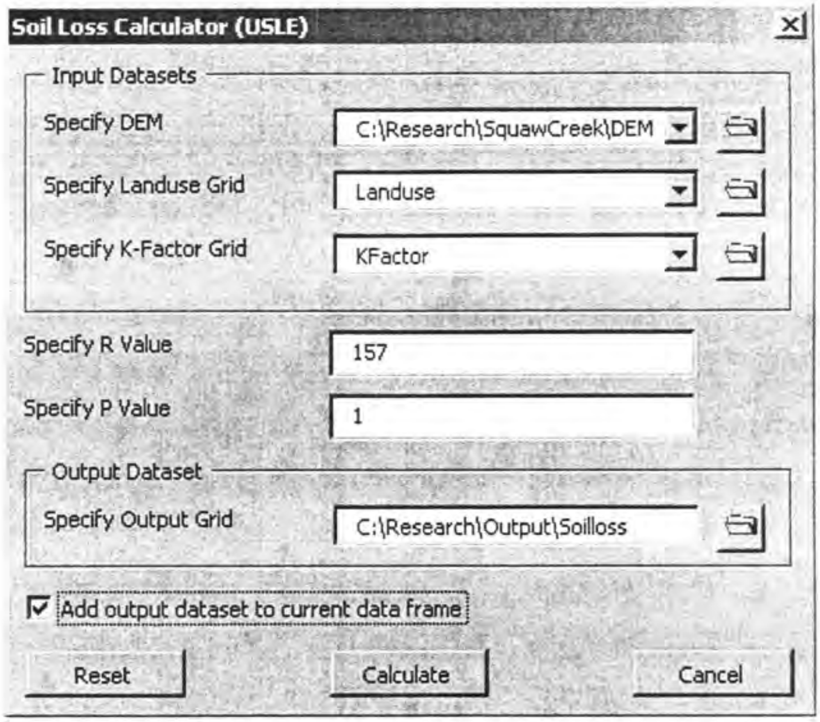

Figure 12: Soil Loss Calculator

First of all the calculator derives the **LS** factor grid for the study area. It does so by reading the **DEM** for the study area and creating two new temporary raster datasets. One dataset contains the values for the slope in percentage and the other one contains the slope in degrees values for each cell of the study area. Based on the values for the slope in percentage, the slope length value for each cell is determined from a look up table (Table 3) embedded within the system. The **LS** value for each cell of the study area is then determined as:

$$LS = (a/22.86)\ \hat{}\ m * (65.41 \sin b\hat{}2 + 4.56 \sin b + 0.065)$$

where ***a*** is the slope length of the site (m), ***b*** is the angle of slope (degrees) and ***m*** is the coefficient related to the ratio of rill to inter-rill erosion.

Table 3: Slope Length by Slope Class

Slope (%)	Slope Length (Meters)
0-2	60.96
2-5	53.34
5-7	45.72
7-10	38.1
10-15	30.48
15-20	22.86
20-60	15.24

Table 4: Land use Types and their Respective C Factor Values

Land Use	C-Factor
Urban and Industrial	0
Farmstead and Rural Residences	0.03
Other Rural Developments	0.03
Cultivated Land	0.24
Grassland	0.05
Deciduous Forest	0.009
Water	0
Wetlands	0
Gravel Pits and Open Mines	0

The calculator generates the crop type factor grid from the land use land cover grid for the study area by using a look up table (Table 4), and gives a numeric value to each cell in the study area. The final output from this calculator is the soil loss grid (Figure 13), which is generated by overlaying the different basic and the derived datasets required as the input and it contains the soil loss values for each cell of the study area. The students can then overlay this soil loss grid on top of their input datasets to visualize the change in soil loss from one cell to another with the change in the various input parameters. They can experiment with varying the input parameters in order to reduce the soil loss and compare the different results. This would allow them to have a better understanding of the processes and issues involved in soil erosion modeling.

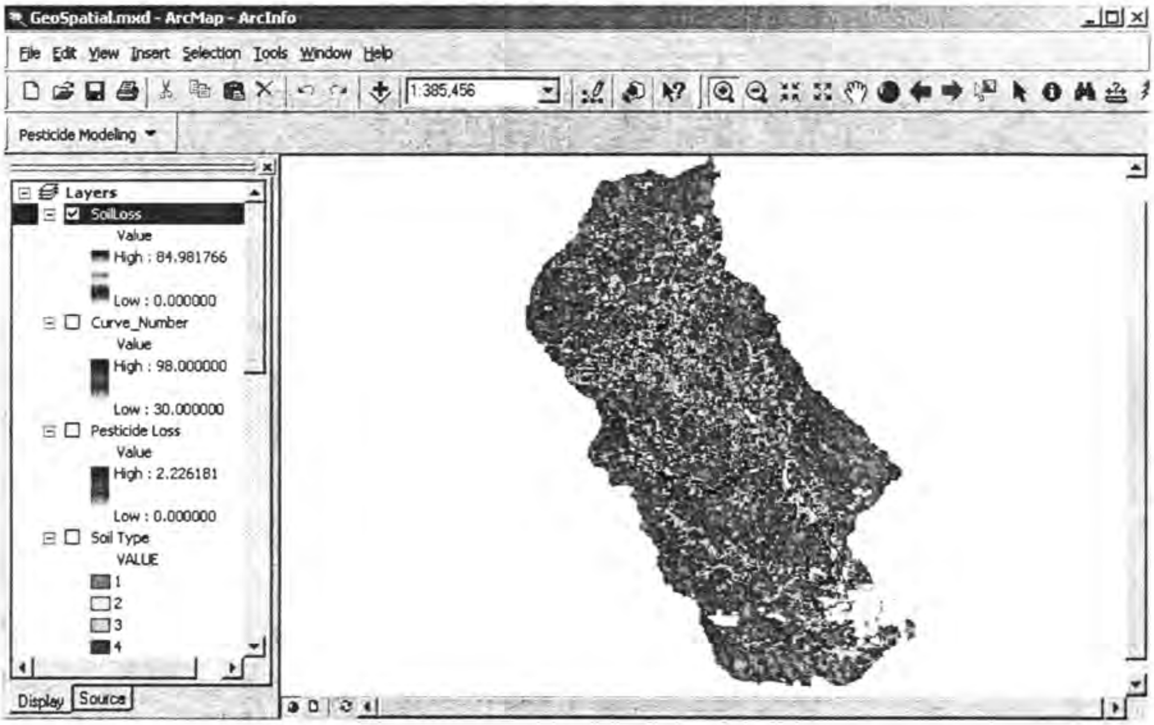

Figure 13: Soil Loss Grid for Squaw Creek Watershed

4.1.4.4 Pesticide Loss Calculator

The final step in this modeling process is the calculation of pesticide loss from the study area on a cell-by-cell basis. To accomplish this task another interface called the Pesticide Loss Calculator (Figure 14) was developed. The inputs to this calculator include the curve number, organic carbon fraction, available water capacity, soil bulk density, soil loss and the pesticide application rate grid for the study area.

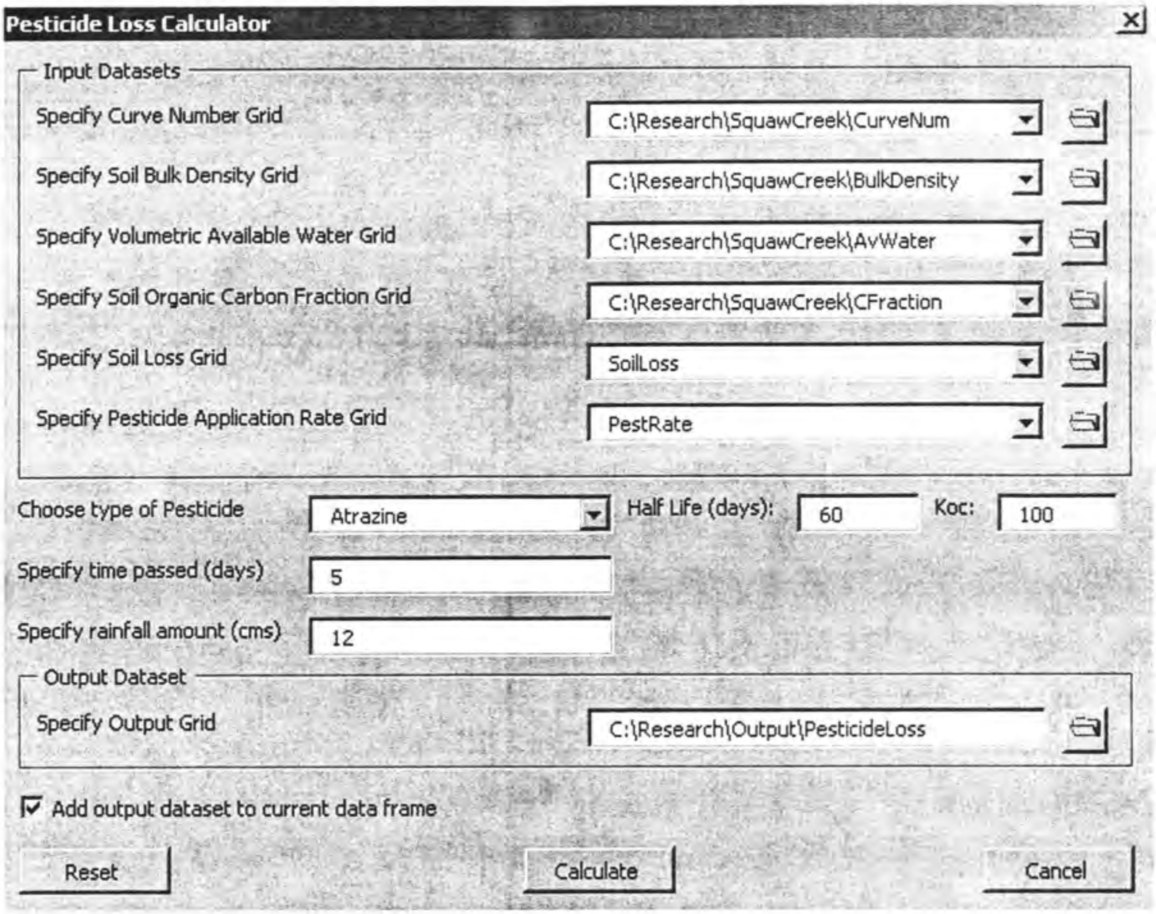

Figure 14: Pesticide Loss Calculator

The calculator allows the student to control the process by determining the type and amount of pesticide to be applied. The student has the option to either select from a list of some commonly used pesticides, information for which has already been fed into the system, or to specify some other pesticide along with its half life and organic carbon partition coefficient values. Next the student specifies the rainfall amount they want to apply to the study area and also the time passed between the pesticide application and the first rainfall event. Once all this information has been fed to the system, it will determine the total pesticide loss (adsorbed phase and dissolved phase) for each cell of the study area and create a new raster (Figure 15), which has these values.

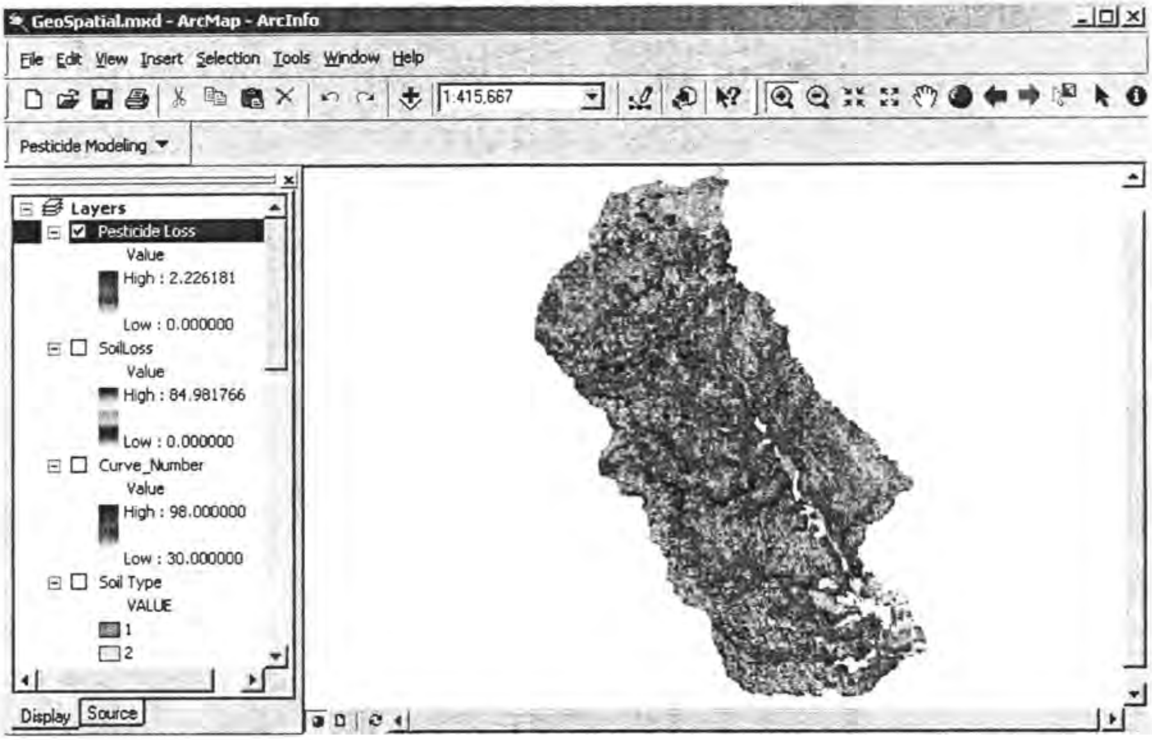

Figure 15: Pesticide Loss Grid for Squaw Creek Watershed

This interactive modeling system provides a valuable tool for planning cost-effective measures to alleviate impacts of pesticide runoff on water quality. Embedding modeling equations inside GIS, which holds large amounts of data on the distribution of land attributes, is useful and essential (Tim et al, 1996). This facilitates the application of the system to large areas, and also improves the user friendliness by eliminating the use of computer programs for input/output data transfer. It simplifies the modeling process and enhances detailed display and visualization of model outputs. The model improves environmental decision making by providing for analysis of "what-if" land-use, land management, and pesticide management options.

4.1.4.5 Web-based Version of the Modeling System

Interactive web-based modeling environments are increasingly being used to support spatially explicit evaluation of impact of human activities on the structure and functioning of watershed ecosystems. The modeling system described in the previous section works well if the learner has access to ESRI's ArcView software, but not otherwise. As a solution to this problem and in order to make the modeling system and with it the virtual learning environment functional under all conditions, a user-friendly, web-based, interactive, event-based pesticide runoff modeling system was developed. To develop the application described in this study, use was made of the ESRI's MapObjects™ software that supports the server-side strategy. Based on the issues mentioned in section 3.4.1, and in order to achieve the research objectives the client-requested (server-side) software architecture was chosen over server-supplied (client-side) software architecture. All the data and the programs/functions reside on the server. The server can handle multiple requests from multiple clients at the same time and can keep record of each client, processing their requests, and sending back the results.

The overall aim was to develop a physically based, interactive, web-based spatially explicit pesticide runoff modeling environment that could be used for resource planning and inquiry-based education and training in environmental/watershed science. Figure 16 shows the architecture of the pesticide-modeling environment. Having this modeling environment available on the Web makes it remotely accessible to a diverse cadre of users (watershed stakeholders, resource planners, and distant learners).

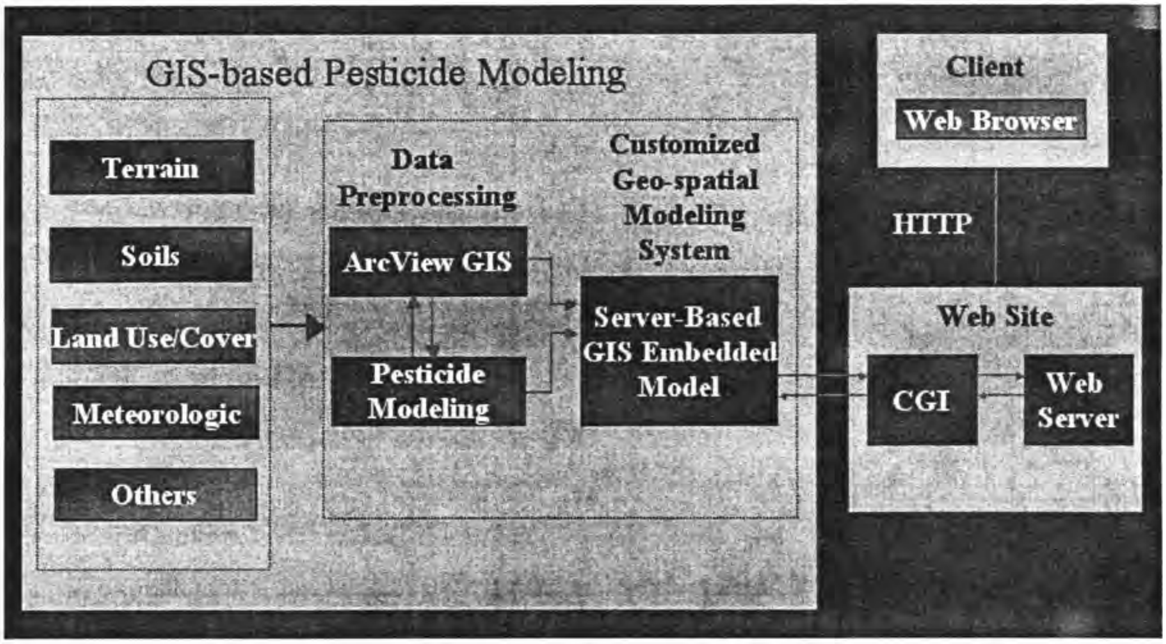

Figure 16: Server-Based Pesticide Modeling Using GIS

The modeling system was made available on the Web using HTML, PERL, and ESRI's MapObjects software. Apache (http://httpd.apache.org) was installed as the server software on the web server computer. The client layer consists of a personal computer running a Web browser. This layer provides the user interface and operates by generating requests to the application server via HTTP and displays the resulting HTML file in a Web browser. The user interface provides an interactive modeling environment that facilitates user access to the modeling components, selection and implementation of modeling options, and display of simulation results (Figure 17). The users can navigate the entire modeling process by making appropriate selections and inputting values in the pull down menus and text boxes on the interface.

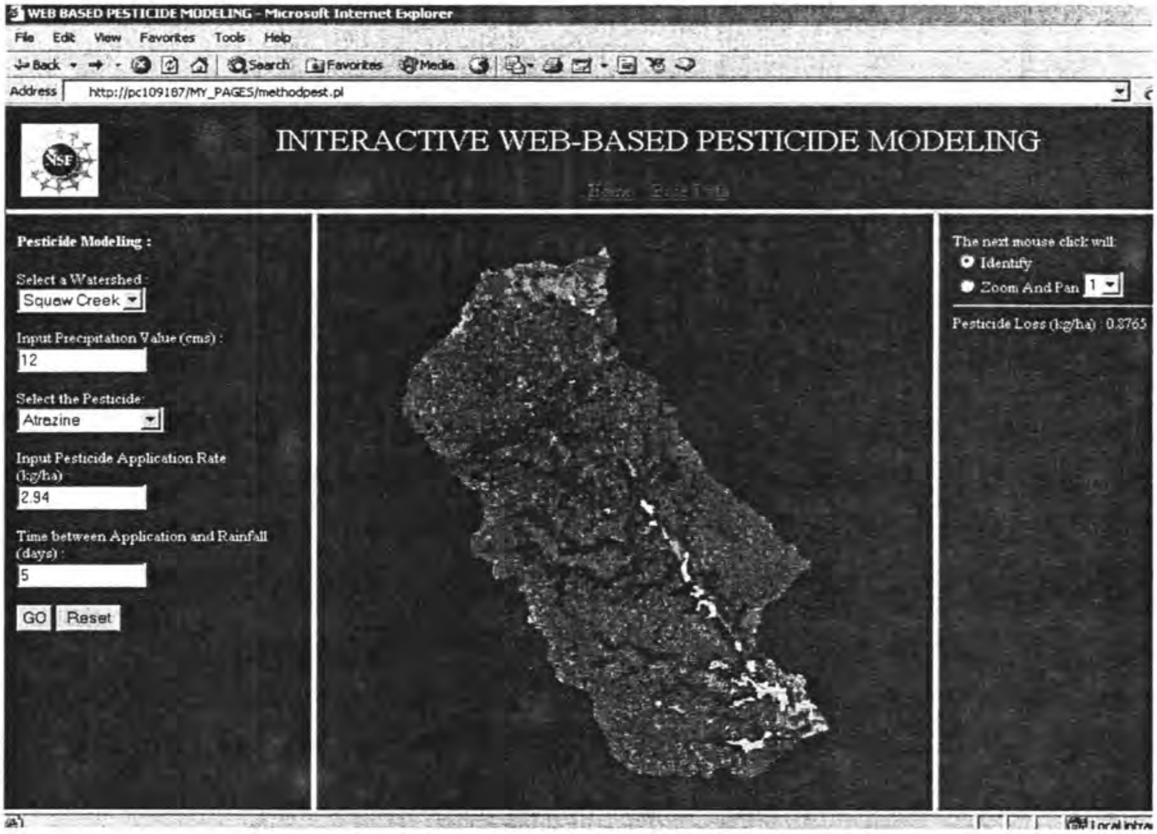

Figure 17: Web-Based Pesticide Modeling

The web-based version also takes raster datasets as input and the output is also a raster that has the pesticide loss values for the whole watershed. There are however, some key differences in the web-based version and the ArcView version of the modeling system. The first difference lies in the structure of the system. In the web version of the modeling system the three modules namely the Curve Number Generator, Soil Loss Calculator and the Pesticide Loss Calculator have been combined into a single simulation-modeling environment. The second difference lies in the fact that since the web-based modeling environment employs the server-side strategy, the learner will be able to work only with the watersheds for which all the required input data has been loaded on to the server.

In addition to pesticide modeling, the environment also provides the learners with the ability to browse the base or the input datasets for the watershed that they want to work with. The learners can send a request for the input datasets and can render them as a single value, unique value or a classified map (Figure 18). The client has the capabilities to zoom in/out and identify features on the generated maps (Figure 19).

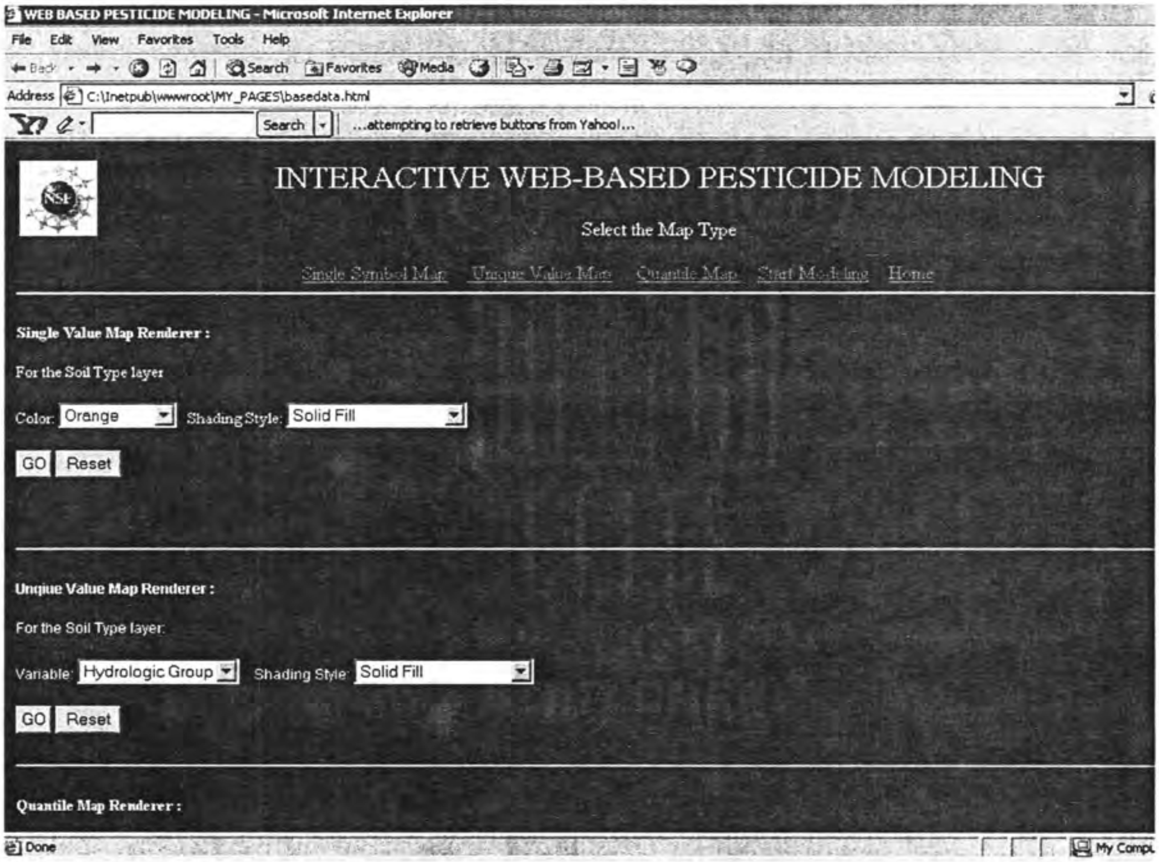

Figure 18: Viewing the Base Datasets

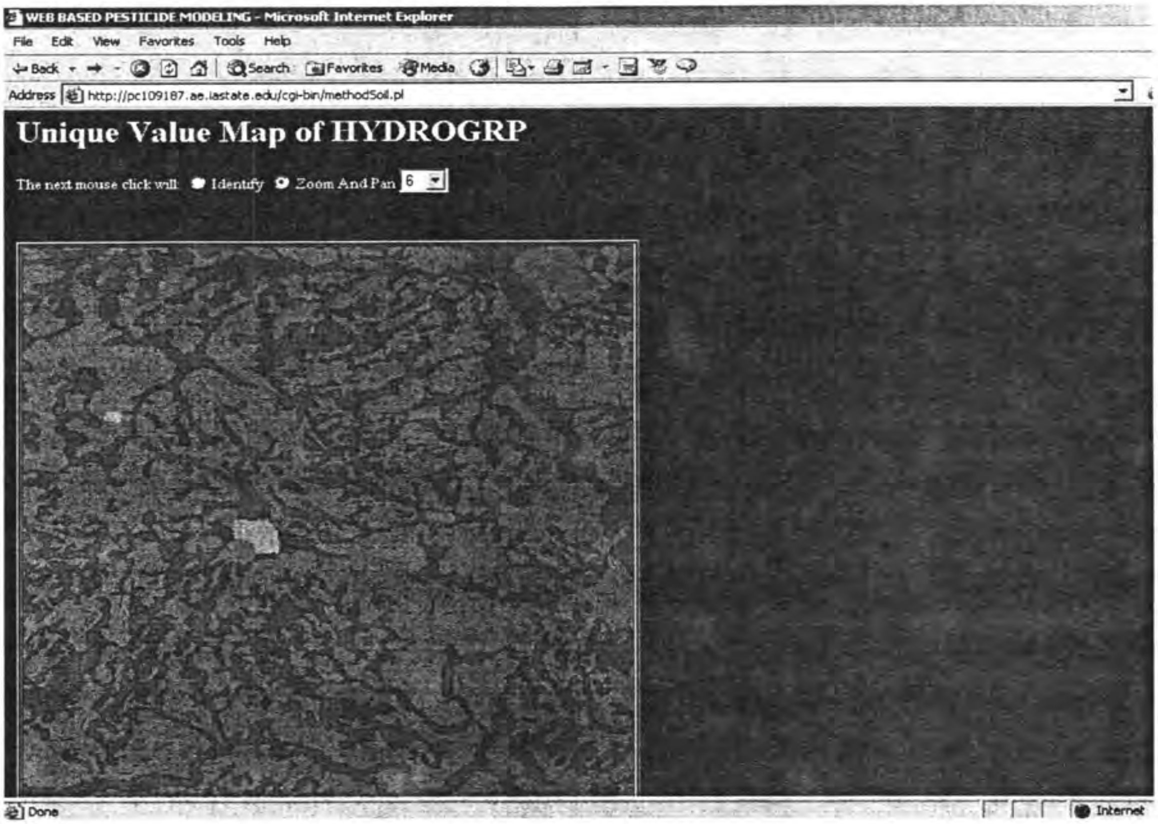

Figure 19: Zoomed-in View for a Map on the Web

This study constitutes one of the many attempts to integrate current and emerging technologies to model and track pesticide transport processes within watersheds and the human activities that affect them. The study integrates simulation modeling, GIS and web-based technologies into an authentic, interactive environment for water quality assessment. The integration of GIS and the Web (or Web-GIS) is a relatively new field and it offers a lot of opportunities for shifting over from the traditional desktop to remotely accessible GIS applications. Many web-GIS applications today allow the user to request a certain kind of map, and then allow him/her to interact (zoom in/out and identify features) with it. In this study a successful attempt has been made to move a step further by allowing for real time modeling on the Web using the various geo-hydrologic datasets. Water quality scientists can use the application for various planning and management purposes. The application being Web-based allows for an improved collaborative environmental decision-making by providing for analysis of "what-if" land-use, land management, and pesticide use options. This application can also be used for training and educating the future environmental scientists who can visualize the processes and learn-by-doing in a more realistic simulated environment. This interactive web-based modeling environment provides a cost-effective way for a spatially explicit evaluation of impact of human activities on the structure and functioning of watershed ecosystems.

CHAPTER 5. SUMMARY and FUTURE DIRECTIONS

This research involved the development of a web-based virtual learning environment (VLE), with a focus on watershed science. The goal was to provide the students with inquiry based, authentic learning materials designed to help them develop spatial/quantitative reasoning and problem solving skills. This is a move towards constructivist pedagogy through increased student participation and a shift of focus in the learning process from the instructor to the student. The developed system gives the students more control over the learning experience, allowing them to determine their educational needs and providing the resources and materials to fulfill them.

The VLE employs the server-side architecture. All the learning modules, the datasets, and the simulation and visualization tools reside on the server. In order to gain access to the VLE, students only require a web-browser and an Internet connection. In order to avoid server overload, the VLE has been configured to restrict access and only the registered students can make use of it. Efforts have also been made to keep the user interface of the VLE simple and easy to navigate.

Watershed science education is multidisciplinary, requiring study of the physical, chemical, biological, and ecological interactions in a drainage basin that affect water resources. It also aims at developing students' skills, knowledge, and competencies in understanding the interrelationships between the biophysical, cultural, and socioeconomic components, and the feedback between humans and the environment. With this in mind, all the learning modules within the VLE have been designed to illuminate the interdisciplinary nature of watershed science by providing the learning materials and simulation and visualization tools that allow students to explore the interrelated human and ecological processes responsible for the problems to be tackled in the environment, economy, and society.

For the simulation and visualization component of the VLE, a web-based geographic information system (GIS) has been developed. Since a GIS can be used to manage and store spatial data, embedding distributed models within a GIS makes that spatial data available for environmental analysis. A cell-by-cell modeling approach has been adopted to provide for exacting analysis. The modeling systems have been designed to hide the complex nature of the environmental processes, so that the students can focus more on understanding the concepts and issues related to watershed management. In support of these simulation tools, a comprehensive watershed digital data library has also been provided.

Future Directions

This research was successful in its attempt to provide for a web-based learning environment for watershed science education. However, there were some limitations in terms of the simulation tools and the datasets that can be used by the students. Since the VLE employs a server-side strategy, the students can make use of only the datasets available on the server. Even though an attempt has been made to provide a comprehensive digital data library, it would be a significant improvement if the students were given the option of using their own datasets as inputs to the modeling systems. One way to do this would be to employ a client-side strategy, but this has its own drawbacks, both with regard to the huge size of the GIS datasets as well as the current software limitations. One way out of this problem would be to have some combination or a hybrid of the server-side and the client-side strategies.

Another improvement or extension to this VLE is moving towards fully immersive environments. Virtual reality applications have long been used extensively in different engineering fields to address a variety of issues related to engineering design and simulation. The use of virtual reality tools in environmental sciences can be in terms visualization of complex ecological data, and in visualizing the effect of management practices on the ecosystems. In environmental/hydrological sciences virtual reality applications can be used quite effectively for training and education.

CHAPTER 6. REFERENCES CITED

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